

# GROSS ERRORS IN THE IPCC-AR4 REPORT REGARDING PAST & FUTURE CHANGES IN GLOBAL TROPICAL CYCLONE ACTIVITY – (*A Nobel Disgrace*)

*by William M. Gray*



SPPI ORIGINAL PAPER



October 11, 2011

## Portion of IPCC-AR4 (page 239)

“Intense TC activity has increased since about 1970.”

(NOT TRUE)

...“Globally, estimates of the potential destructiveness of hurricanes show a significant upward trend since the mid-1970s, with greater storm intensity. Such trends are strongly correlated with tropical SST.”

(NOT TRUE)

“These relationships have been reinforced by findings of a large increase in numbers and proportion of hurricanes reaching categories 4 and 5 globally since 1970 (NOT TRUE) .... The largest increase was in the North Pacific, Indian and southwest Pacific Oceans.”

(NOT TRUE)

The Four IPCC reports have emboldened our politicians to come forth with the following erroneous statements –

Al Gore states in his book and movie – An Inconvenient Truth – “major storms (hurricanes) spinning in both the Atlantic and Pacific Oceans since the 1970s have increased in duration and intensity by about 50 percent.”

(NOT TRUE)

In November 2008 President-Elect Barack Obama said, “storms (i.e. hurricanes) are growing stronger with each passing hurricane season.”

(NOT TRUE)

# TABLE OF CONTENTS

ABSTRACT .....	5
ABOUT THE AUTHOR.....	5
ACRONYMS, ABBREVIATIONS AND DEFINITIONS.....	6

## PART I - HISTORY AND POLITICS

1. INTRODUCTION .....	7
2. BRIEF SUMMARY OF REASONS NOT TO BELIEVE A HUMAN INFLUENCE ON TROPICAL CYCLONES (TCs) – IN CONTRADICTION TO THE IPCC-AR4 REPORT.....	9
3. THE BURST OF US HURRICANE DAMAGE IN 2004-2005.....	13
4. SUMMARY OF SOME OF THE ERRONEOUS AND OUTRAGEOUS STATEMENTS WHICH SET THE BACKGROUND TONE FOR THE IPCC-AR4 STATEMENTS ON TCs.....	16
5. THE IPCC-AR4'S CHAPTER 3 WHICH DISCUSSED TROPICAL CYCLONES.....	27
6. IGNORING THE UN-WMO TC WORKSHOP OF 2006.....	30
7. MOONEY'S JUDGMENTS.....	31
8. PRESTIGIOUS SCIENTISTS WHO HAVE ADVOCATED OR SUPPORTED AN INFLUENCE OF RISING LEVELS OF CO <sub>2</sub> ON TC ACTIVITY.....	35

## PART II - SCIENTIFIC DISCUSSION

9. CO <sub>2</sub> 'S MINISCULE ENERGY INFLUENCE ON TC ACTIVITY .....	38
10. WHY LONG-PERIOD CHANGES IN GLOBAL SST SHOULD HAVE LITTLE INFLUENCE ON LAPSE- RATE CONDITION OR TC ACTIVITY .....	40
11. FUNDAMENTAL IMPORTANCE OF CONVECTIVE DOWNDRAFTS AND MASS RECYCLING WITHIN ORGANIZED TROPICAL SYSTEMS .....	53

12. GLOBAL RAINFALL'S STIMULATION OF RADIATION ENERGY TO SPACE (IMPLICATIONS FOR CLIMATE PREDICTION AND GLOBAL WARMING .....	66
13. IPCC-AR4'S OMISSION OF THE CAUSES OF THE LARGE MULTI-DECADAL VARIATIONS IN ATLANTIC BASIN MAJOR HURRICANES AND US LANDFALL .....	75
14. THE OCEAN AS A POWERFUL MODULATOR OF GLOBAL CLIMATE AND ATLANTIC MAJOR HURRICANE ACTIVITY.....	85
15. DISCUSSION.....	90
16. AUTHOR'S CLIMATE VIEWS AND RECOMMENDATIONS.....	94
FIGURE AND GEORGE WILL QUOTE.....	95
17. BIBLIOGRAPHY .....	96
18. ACKNOWLEDGEMENT .....	101
19. APPENDICES – (A, B, C, AND D) .....	101

# **GROSS ERRORS IN THE IPCC-AR4 REPORT REGARDING PAST & FUTURE CHANGES IN GLOBAL TROPICAL CYCLONE ACTIVITY – (A NOBEL DISGRACE)**

*by William M. Gray | October 11, 2011*

## **ABSTRACT**

The United Nation's Intergovernmental Panel on Climate Change (IPCC) Assessment Report Four (AR-4) of 2007, concerning the influence of rising levels of CO<sub>2</sub> on global increases of tropical cyclone (TC) activity is inaccurate and a disgrace to the scientific community. The public expected there would be rigor and objectivity coming out of such an important document which shared a Nobel Peace Prize with former US Vice President Al Gore. The summary of TC activity of this report was based on discredited peer-reviewed papers whose lack of authenticity was known before the report was released. A select cadre of global warming advocates (with little TC knowledge or experience) bent their objectivity to drive this report toward a desired (but faulty) conclusion that global TC activity was increasing in frequency and intensity. They further implied that a large portion of this alleged TC increase could likely be attributed to rising levels of CO<sub>2</sub>.

This paper brings forth observational and theoretical evidence to show that rising levels of CO<sub>2</sub> have not had any observable association with increases in global tropical cyclone frequency and intensity. In fact, levels have been trending downward over the last 20 years. This paper discusses why we should not be able to measure any potential future CO<sub>2</sub>-TC association for many decades, and if any such potential future relationship should ever be able to be isolated, it would be quite small. It also dissects the many observational and theoretical errors of the IPCC-AR4 concerning its reported past and likely future increases of global TC activity.

This paper extends the list of IPCC-AR4's many questionable conclusions and misrepresentation beyond those that have already been earlier pointed out such as the Himalayas becoming snow-free by 2035, the Arctic Ocean possibly becoming ice-free in coming decades, and the possible coming Amazon rainforest destruction. The issuance of these erroneous IPCC reports does much damage. They should be terminated.

## **ABOUT THE AUTHOR**

I have been studying, teaching and forecasting tropical cyclones (TCs) for over 55 years. I hold MS and Ph.D. degrees in meteorology and geophysical science from the University of Chicago. Both my MS and Ph.D. theses were on TC topics. I had my first research aircraft flight into a hurricane in 1958. I have been the major advisor to 50 MS and 20 Ph.D. students, the majority of whose theses were on hurricane-related subjects. I was delegated to conduct a personal UN-WMO sponsor survey trip of all the 28 global TC forecast and research centers in 1977-78. I organized the first UN-WMO International Workshop on TCs (IWTC) workshop in Bangkok in 1985 and attended the following five workshops. I instigated and have been involved with the issuing of seasonal Atlantic basin hurricane forecasts for the last 28 years. These forecasts have had extensive coverage from the media. I am presently an Emeritus Professor in the Department of Atmospheric Science at

Colorado State University where I have been in residence since 1961. I continue to work full time and live off of my retirement income. I have a small research staff of three individuals. My project and I have never received any research support from the fossil-fuel industry. We presently receive no federal grant support of any type. This report has been totally funded from the author's personal resources.

Many of my similarly experienced TC colleagues and I were never approached by the IPCC for our views on possible future changes in the number or intensities of TCs. This was likely because many of us had earlier demonstrated open skepticism of the Anthropogenic Global Warming (AGW) hypothesis as a significant factor for global warming or in TC alteration.

I write this paper to try to bring some reality to this topic that has been so badly abused by those willing to bend their objectivity in order to ride the human-induced global warming bandwagon for research grants, publicity, or other desired goals. Having devoted my entire career to atmospheric science (particularly TCs), I feel I have an obligation to speak out on an issue involving my expertise. I would feel guilty if I did not do so. My formal Vita is at the end of this write-up.

## ACRONYMS, ABBREVIATIONS AND DEFINITIONS

<b>TC</b>	<u>T</u> ropical <u>C</u> yclone. This includes any named tropical cyclone whether of tropical storm, hurricane or typhoon, or major hurricane or super typhoon intensity.	<b>SST</b>	<u>S</u> ea <u>S</u> urface <u>T</u> emperature.
<b>RH</b>	<u>R</u> elative <u>H</u> umidity.	<b>IPCC</b>	<u>I</u> ntergovernmental <u>P</u> anel on <u>C</u> limate <u>C</u> hange.
<b>Cb</b>	<u>C</u> umulonim <u>b</u> us or thunderstorm cloud extending through most of the troposphere.	<b>IPCC-AR4</b>	IPCC Assessment report #4 (2007).
<b>PBL</b>	<u>P</u> lanetary <u>B</u> oundary <u>L</u> ayer. This is the frictional or mechanically mixed lower atmospheric layer which extends from the surface to 0.5 to 1.0 km altitude. Relative to tropical cyclone it is the layer from the surface to cumulus cloud base (~ 600 m or 950 mb).	<b>IH or MH</b>	<u>I</u> ntense <u>H</u> urricane or <u>M</u> ajor <u>H</u> urricane. Saffir-Simpson category 3 to 5 intensity or substantial maximum surface winds $\geq 115$ mph or $\geq 96$ knots.
		<b>THC</b>	Atlantic Ocean <u>T</u> hermohaline <u>C</u> irculation.
<b>AGW</b>	<u>A</u> nthropogenic <u>G</u> lobal <u>W</u> arming.	<b>AMO</b>	<u>A</u> tlantic <u>M</u> ulti-decadal <u>O</u> scillation (another name for the THC).
<b>ACE</b>	<u>A</u> ccumulated <u>C</u> yclone <u>E</u> nergy ( $\Sigma V_{\max}^2$ ).	<b>MOC</b>	<u>M</u> eridional <u>O</u> verturning <u>C</u> irculation.
<b>Wm<sup>-2</sup></b>	Watts per meter squared. Unit of energy ( $1 \text{ Wm}^{-2} = 2 \text{ Cal/cm}^2\text{d}$ ).	<b>IR</b>	<u>I</u> nfr <u>a</u> red or longwave radiation energy.
<b>Cal/cm<sup>2</sup>d</b>	Calorie/cm <sup>2</sup> day. Unit of energy.	<b>OLR</b>	<u>O</u> utgoing <u>L</u> ongwave <u>R</u> adiation.

**UNDERSTANDING ENERGY UNITS.** The 'Watt' is currently the unit of power in use. 1 Watt equals 0.24 calories of heat per second. Watts per meter squared ( $\text{Wm}^{-2}$ ) is the common unit of energy. One  $\text{Wm}^{-2}$  is the energy equivalent of about 2 calories per square centimeter per day ( $\text{cal/cm}^2\text{d}$ ). One  $\text{Wm}^{-2}$  will warm one gram of water by  $2^\circ\text{C}$  in one day. It takes  $125 \text{ Wm}^{-2}$  of energy to warm the atmosphere  $1^\circ\text{C}$  in one day. This is equivalent to the energy needed to warm 2.5 meters depth of water by  $1^\circ\text{C}$  in one day.

## **PART I – HISTORY AND POLITICS**

### **1. INTRODUCTION**

The US government has expended billions of dollars in recent years to promote the questionable idea that human-induced increases in atmospheric  $\text{CO}_2$  will cause dangerous changes to the global climate system. Massive government and media campaigns have been launched to promote the dangers of  $\text{CO}_2$ -induced anthropogenic global warming (AGW) and related influences such as the anticipated increases in global tropical cyclone (TC) frequency and intensity as well as other severe weather events. Pro-AGW advocates have pushed to have this warming gospel accepted across the world and taught to our children in their regular school programs. AGW advocates want to worry the public as much as possible in order to be better able to increase their influence and funding support.

There has yet to be an open and honest scientific debate on the future consequences of  $\text{CO}_2$  increases and of the potential social and negative economic consequences of efforts to slow down  $\text{CO}_2$  increases. A number of pro-AGW advocates have expended considerable efforts in recent years to develop theories and in arranging TC data in order to show that global TCs are increasing in frequency and intensity in response to rising  $\text{CO}_2$  levels. Global warming advocates have had a strong desire to find and to exploit increases in TC activity as further evidence of the human-induced warming scenarios.

The IPCC hierarchy had its mind made up years ago that they would make every attempt possible to link rising levels of  $\text{CO}_2$  with increases in global hurricane intensity and frequency. They knew that if such an association could be established in the public's mind that this could be used to help scare and induce the public (and Congress) into funding the political, economic, and environmental agendas of a large number of special interest groups. Input from skeptics or any hypothesis or data that did not link rises in  $\text{CO}_2$  to increases in TC activity was to be avoided, suppressed, or rejected. The IPCC deliberately ignored the most experienced and knowledgeable TC experts in order to preserve their desired goal of propagandizing the public to believe that rising  $\text{CO}_2$  levels were creating a growing hurricane threat. Most of the IPCC statements on TCs, as will be shown, are not supported by observations.

After the very severe US hurricane landfalling seasons of 2004 and 2005, the public was more open and vulnerable to such arguments of  $\text{CO}_2$  induced increases in hurricane activity. A group of papers were rapidly published to exploit and to justify this assumption so that the authors

might be able to jump onto the warming bandwagon and increase their potential for more federal grant support, publicity, and other envisioned gains.

These papers strived to arrange their observations and physical explanations in ways to show or imply a direct association between increasing levels of TC activity with increasing sea surface temperatures (SSTs) and rising levels of CO<sub>2</sub>. The majority of these authors who rapidly published papers between 2005-2008 had little background experience in TC research or forecasting, or in TC climatology. Nearly all of these papers were biased in the direction of implying more TC activity with rising levels of SST. Most of these papers should not have been able to get through the peer-review process. The journal editors of these papers appear to have sent them for review to known like-minded AGW sympathizers. Many of our country's most experienced TC researchers and forecasters appear to have been left out of this review process.

Following these two disastrous US landfalling hurricane years of 2004-2005, the mainstream media (without a background knowledge of TCs and preconditioned to accept the AGW arguments) generally accepted the reality of these paper's faulty results. This created a near panic among coastal residents over the implied coming increase of hurricane destruction that these papers indicated was on the way. Disaster stories made good press and fit in very well with the government and environmentalists' AGW scenarios. The media, in general, chose not to discuss the views of established TC researchers and forecasters from the National Hurricane Center and many of my experienced TC colleagues who did not subscribe to such disaster scenarios.

I have been closely following the AGW debate for the last 25 years. It has been politically dominated from the start. All four IPCC reports have been slanted to support the AGW hypothesis. There has been much valuable data and analysis contained in these four reports that have been issued, but the report's summaries have always been biased toward the organizers desired goal of saying to government policy makers that CO<sub>2</sub> was causing increases in both global temperature, TC activity, severe weather events, etc.

I believe that rising levels of CO<sub>2</sub> will manifest itself through a small enhancement of the global hydrologic cycle (by a few percent) but that we will see very little increase of global temperature when CO<sub>2</sub> amounts double towards the end of the 21<sup>st</sup> century. The General Circulation Models (GCMs) on which predictions of 2-5°C (4-9°F) global warming for a doubling of CO<sub>2</sub> are based have basic flaws and they should not be accepted. The four IPCC reports which have been issued over the last 16 years have done much harm in needlessly alarming the world over the dangers of rising levels of CO<sub>2</sub> that are not realistic. The IPCC process has made it impossible to separate the overwhelming political nature of this effort from the desired unbiased scientific analysis.

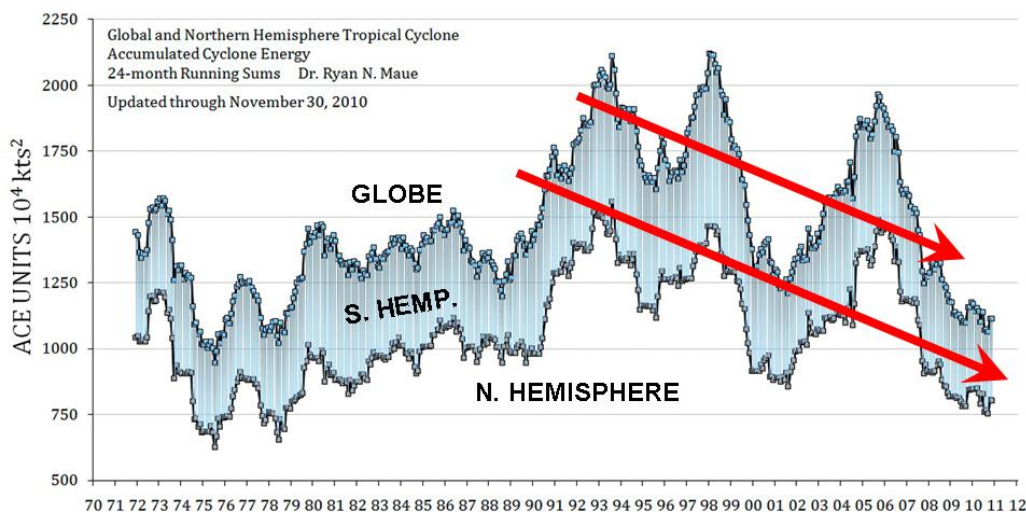
This paper documents many of the false statements on tropical cyclones which were contained in the IPCC-AR4 and gives scientific arguments why rising levels of CO<sub>2</sub> should have little or no significant influence on TC activity and only marginally so on global warming.

## 2. BRIEF SUMMARY OF REASONS NOT TO BELIEVE A HUMAN INFLUENCE ON TROPICAL CYCLONES (TCs) – IN CONTRADICTION TO THE IPCC-AR4 REPORT (SEE PART II, SECTIONS 9-14, FOR A MORE DETAILED SCIENTIFIC DISCUSSION.)

This section briefly discusses:

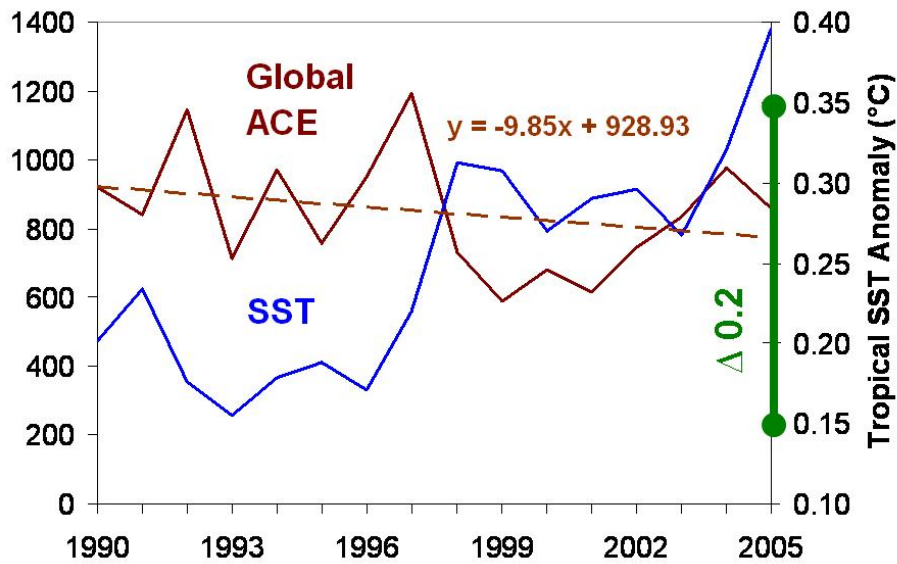
- Last 20-year downward trend in global TC activity.
- CO<sub>2</sub>'s extremely small relative energy influence.
- Lack of SST vs. TC activity correlation.
- Atlantic Ocean thermohaline circulation (THC) influence on Atlantic SST variations.

**LAST 20-YEAR DOWNWARD TREND IN GLOBAL TC ACTIVITY.** Although global surface temperatures appear to have increased during the 20<sup>th</sup> century by about 0.65°C or 1°F, there is no reliable data to indicate that increases in TC frequency or intensity changes occurred in any of the globe's TC basins. Global Accumulated Cyclone Energy (ACE)<sup>1</sup> shows significant year-to-year and decadal variability over the past 40 years (when global TC data is deemed reasonably reliable) but no period-long increasing trend. In fact, global TC activity has shown (red line) a distinct decrease over the last 20 years when CO<sub>2</sub> amounts were increasing (Figure 2.1). Similarly, Klotzbach (2006) found no significant change in global TC activity during the period from 1986-2005 when tropical SSTs and CO<sub>2</sub> amounts were rising (Figure 2.2). See section 13 for more discussion.



**Figure 2.1** – Northern Hemisphere, Southern Hemisphere, and Global Accumulated Cyclone Energy (ACE) over the period from 1971-2010. Figure has been adapted from R. Maue (2011) at the Naval Research Lab., Monterey, CA.

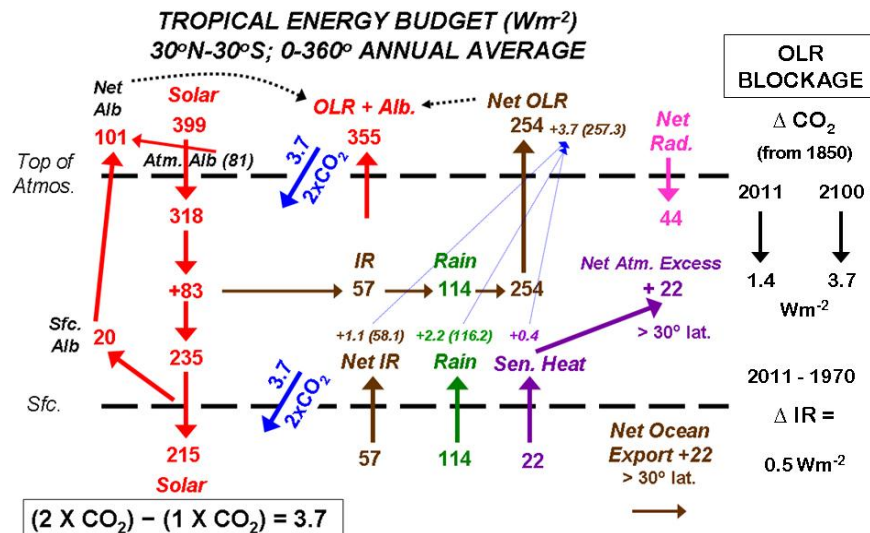
<sup>1</sup> The yearly sum of the square of all named TC maximum winds ( $V_{\max}$ ) at each 6-hour period.



**Figure 2.2** – Global ACE values for 1990-2005 (brown line). A linear trend has been fitted to global ACE. Five-year running mean tropical NCEP Reanalysis SST anomalies (23.5°N-23.5°S, all longitudes) blue line. The base period for tropical SSTs is 1951-1980. Figure adapted from Klotzbach, 2006.

**CO<sub>2</sub>'s EXTREMELY SMALL RELATIVE ENERGY INFLUENCE.** The energy change that will be brought about by rising levels of CO<sub>2</sub> have been and will be for many decades far too small to cause a detectable influence on TCs. Figure 2.3 shows a vertical cross-section of the annual energy budget for the tropics (30°N-30°S; 0-360°). Note how large the surface, troposphere, and top of the atmosphere energy flux components are in comparison with the reduced infrared (IR) flux to space of 3.7 Wm<sup>-2</sup> for a doubling of CO<sub>2</sub> that is expected to occur by the end of the 21<sup>st</sup> century. We are now about one-third of the way (~ 1.4 Wm<sup>-2</sup>) to a doubling of CO<sub>2</sub> from the background state of the mid-19<sup>th</sup> century. Any potential CO<sub>2</sub> influence on TCs will be too miniscule to be isolated, and we do not know if once an influence is ever able to be detected whether it will have a positive or a negative effect on TC intensity and/or frequency.

**LACK OF SST vs. TC ACTIVITY CORRELATION.** These two parameters are only slightly related in all global TC basins besides the Atlantic (Figure 2.4). Long-period SST increases should not be expected to bring about significant global lapse-rate buoyancy increases or enhanced deep cumulonimbus (Cb) convection. If global surface temperature and surface moisture changes on a climate time scale do occur, so too will upper-level temperature and moisture conditions change in a way so as to maintain global rainfall and energy budgets near their long-period average. With global warming or cooling of but a degree or so it is to be expected that average global lapse-rates and TC activity will not appreciably change.



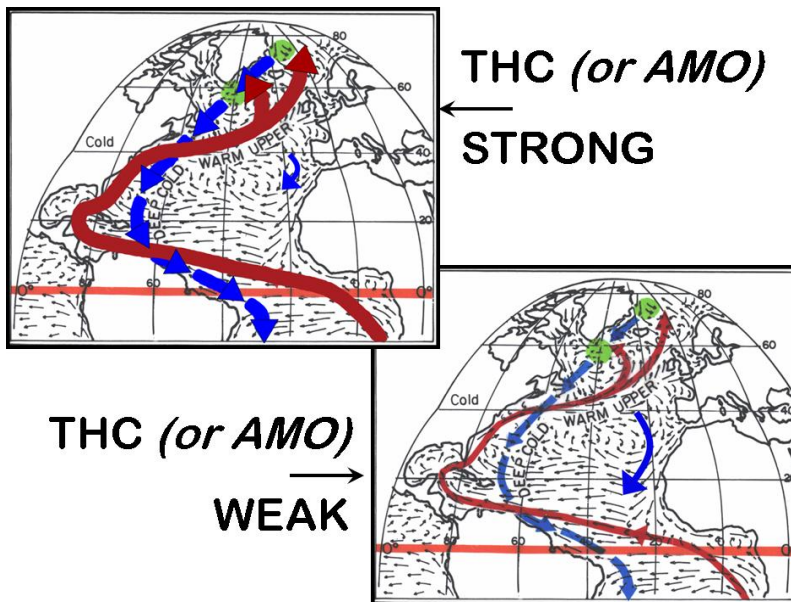
**Figure 2.3** – Vertical cross-section of the annual tropical energy budget as determined from a combination of International Satellite Cloud Climatology Project (ISCCP) and National Center for Environmental Prediction (NCEP) Reanalysis data over the period of 1984-2004. Abbreviations are IR for longwave infrared radiation, OLR for outgoing longwave radiation and Alb for albedo. The tropics receive an excess of about 44  $Wm^{-2}$  which is exported to latitudes poleward of 30°. Estimates are that about half (22  $Wm^{-2}$ ) is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small an OLR blockage has occurred up to now due to  $CO_2$  increases ( $\sim 1.4 Wm^{-2}$ ) and how relatively small is the blockage of 3.7  $Wm^{-2}$  units of energy (left side in blue) in comparison to the much larger other energy terms. The recent  $CO_2$  buildup (1970 to 2011 – lower right) is too small ( $\sim 0.5 Wm^{-2}$ ) to have had any type of a known detectable influence on TCs.

	Yearly Mean ACE	ACE vs. SST Correlation
Northeast Pacific SST (10-15°N)	134	0.01
Northwest Pacific SST (10-15°N)	310	-0.30
S. Hemisphere SST (10-15°S; 50°E-135°W)	205	0.23
Globe SST (20°N-20°S)	769	-0.08

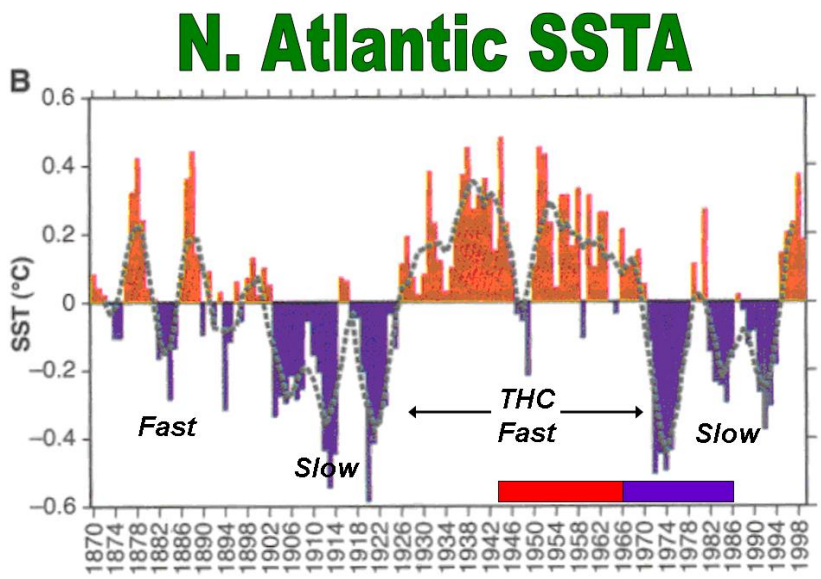
**Figure 2.4** – Correlation of yearly accumulated cyclone energy (ACE) with late summer-early fall sea surface temperature (SST) in three large non-Atlantic TC basins. (ACE data from R. Maue, 2011)

**ATLANTIC OCEAN THERMOHALINE CIRCULATION (THC) INFLUENCE ON ATLANTIC SST VARIATIONS.** The Atlantic Ocean undergoes significant multi-decadal variability in SST due to the strong multi-decadal variability of the Atlantic Thermohaline Circulation (THC) (Figure 2.5). Changes in this oceanic THC are driven by naturally occurring Atlantic salinity variations which cause multi-decadal variations in Atlantic SST, surface pressure, upper level winds, middle-level moisture, and other climate fields which are associated with TC activity.  $CO_2$  or other radiation

changes play little or no role in such oceanic circulation alterations. Figure 2.6 and 2.7 illustrate how well related are the frequency of multi-decadal variations of Atlantic major (Cat 3-4-5) hurricane activity and North Atlantic SST. Note in Figure 2.7 how large the multi-decadal variations in Atlantic major hurricane activity have been over the last century.

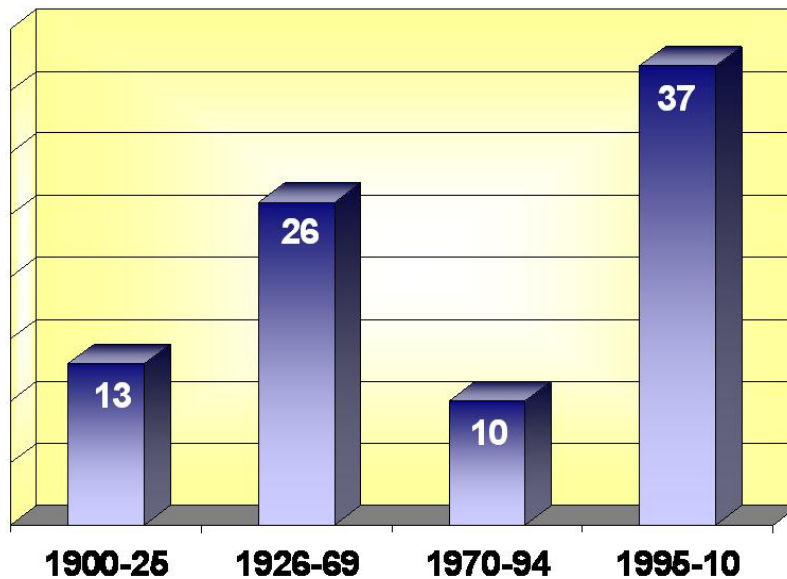


**Figure 2.5** – Illustration of strong (top) and weak (bottom) phases of the Atlantic Thermohaline Circulation (THC) or the Atlantic Multidecadal Oscillation (AMO) as it is sometimes called.



**Figure 2.6** – Long-period portrayal (1870-2006) of North Atlantic sea surface temperature anomalies (SSTA) from a multi-century mean upward sloping curve. The red (warm) periods are when the THC is stronger than average and the blue periods are when the THC is weaker than average. (50-65°N; 10-50°W).

## Annual Number of 6 Hour Periods for Cat. 3-4-5 Hurricanes in the Atlantic



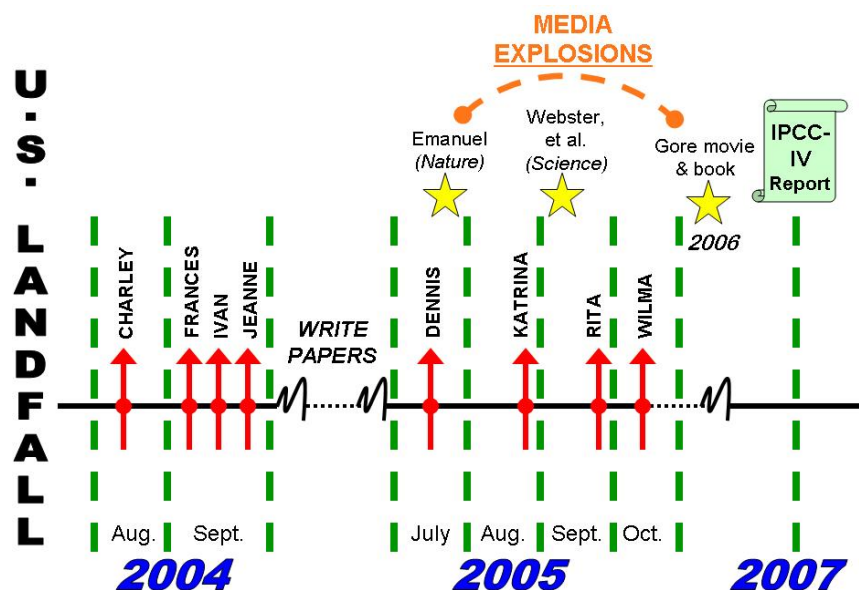
**Figure 2.7** – Multi-decadal comparison of the average number of Atlantic basin annual 6-hour reports of major (Cat. 3-4-5) hurricane activity. The two earlier periods may be somewhat of an underestimate.

### 3. THE BURST OF US HURRICANE DAMAGE IN 2004-2005

The large increase in Atlantic basin major hurricane (MH) activity beginning in 1995 coincided very well with the onset of the strong phase of the THC. For the first nine years (1995-2003) of this recent strong THC the US was very fortunate to have had only three major hurricane strikes (Opal, 1995; Fran, 1996; and Bret, 1999) despite the 32 Atlantic major hurricanes of this period (almost triple the annual number of the 1970-1994 period) that were present in the Atlantic basin during this 9-year period.

But these 9 years of good fortune ended abruptly in 2004 when Major Hurricanes Charley, Frances, Ivan and Jeanne severely impacted Florida and the southeast United States. Then, in the following year, major hurricanes Dennis, Katrina and Rita walloped the Gulf Coast while Wilma devastated south Florida (see Figure 3.1). This double-year whammy of eight intense landfalling TCs (7 of them major hurricanes at landfall) appeared to convince many people who were unfamiliar with the long history of hurricanes that a new era in hurricane destruction was emerging that was a result of human-induced increases in CO<sub>2</sub>. There were many prominent scientists (that should have known better), politicians, environmentalists, and others who were willing to go down this road. And the media, wanting alarmist stories to write about, exaggerated and embellished what the AGW- biased 'scientific experts' had to say. Wanting the most sensational stories the main-stream media chose, in general, not to cover what our country's more experienced TC specialists were saying. Reports that CO<sub>2</sub> was not making hurricanes worse were less newsworthy. This unique two-year US hurricane onslaught along with the growing public belief in CO<sub>2</sub>-induced AGW beckoned exploitation by a number of

groups who were ignorant of the science involved or who saw the opportunity to utilize the public's lack of knowledge on climate and TCs for their own benefit.



**Figure 3.1** – Graphical portrayal of the timing of 8 intense US land-falling hurricane events of 2004-2005, as well as pivotal papers, books and movies that followed.

Many university and governmental scientists saw this as an opportunity to capitalize on the public's gullibility, the media's desire to exaggerate, and the government's science funding agencies wish to give grants to those who believed in the AGW hypothesis. Many scientific papers were rapidly written and published to utilize this special opportunity to join in and participate in the AGW bandwagon and garnish more research grants and publicity that went along with such participation. A flood of TC research papers were written following these two very damaging hurricane years. A sample of these papers is listed in Table 3.1.

**Table 3.1** – Some of the papers published during or shortly after the 2004-2005 hurricane seasons advocating rising CO<sub>2</sub> levels as a likely cause or influence on rising SST and rising global TC frequency and intensity.

1. Anthes, R. A., R.W. Corell, G. Holland, J. W. Hurrell, M. MacCracken, K.E. Trenberth, 2006: Hurricanes and Global Warming: Potential Linkages and Consequences. <i>Bull. Amer. Meteor. Soc.</i> , 87, 623-628.
2. Barnett, T.P., et al., 2005: Penetration of human-induced warming into the world's oceans. <i>Science</i> , 309, 284-287.
3. Curry, J.A., P.J. Webster and G.J. Holland, 2006: Mixing politics and science in testing the hypothesis that greenhouse warming is causing a global increase in hurricane intensity. <i>Bull. Amer. Meteor. Soc.</i> , 87 (8): 1025.
4. Elsner, J.B., 2006: Evidence in support of the climate change-Atlantic hurricane hypothesis. <i>Geophys. Res. Lett.</i> , 33, L16705, doi:10.1029/2006GL026869.
5. Elsner, J.B., Tsonis, A.A. and Jagger, T.H., 2006: High frequency variability in hurricane power dissipation and its relationship to global temperature, <i>Bull. Amer. Meteor. Soc.</i> , 87, 763-768.

6. Emanuel, K.A., 2005: Increasing destructiveness of TCs over the past 30 years. <i>Nature</i> , 436, 686-688.
7. Emanuel, K.A., 2008: The Hurricane-Climate Connection. <i>Bull. Amer. Meteor. Soc.</i> , 89, ES10-ES20.
8. Held, I.M. and B.J. Soden, 2006: Robust responses of the hydrological cycle to global warming. <i>J. Climate</i> , 19(14), 3354-3360.
9. Holland, G. J. & Webster, P. J., 2007: Heightened TC activity in the North Atlantic: natural variability or climate trend? <i>Phil. Trans. R. Soc. A</i> , doi:10.1098/rsta.2007.2083.
10. Holland, G. J., 2007: Misuse of landfall as a proxy for Atlantic TC activity. <i>EOS Trans. Amer. Geophys. Union</i> , 88, 349-350, doi: 10.1029/2007EO36001.
11. Hoyos, C.D., P.A. Agudelo, P.J. Webster, J.A. Curry, 2006: Deconvolution of the factors contributing to the increase in global hurricane intensity. <i>Science</i> , 312 (5770): 94-97.
12. Knutson, T.R., and R.E Tuleya, 2004: Impact of CO <sub>2</sub> -induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. <i>J. Climate</i> , 17(18), 3477-3495.
13. Knutson, T.R., J.J. Sirutis, S.T. Garner, I. Held, and R.E. Tuleya, 2007: Simulation of the Recent Multidecadal Increase of Atlantic Hurricane Activity Using an 18-km-Grid Regional Model. <i>Bull. Amer. Meteor. Soc.</i> , 88(10), doi:10.1175/BAMS-88-10-1549.
14. Knutson, T. R., Sirutis, J. J., Garner, S. T., Vecchi, G. A. & Held, I. M., 2008: Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions. <i>Nature Geosci.</i> 1, 359–364.
15. Mann, M.E., Emanuel, K.A., 2006: Atlantic Hurricane Trends linked to Climate Change. <i>EOS</i> , 87, 24, p 233, 238, 241.
16. Mann, M.E., Sabbatelli, T.A., Neu, U., 2007: Evidence for a Modest Undercount Bias in Early Historical Atlantic TC Counts, <i>Geophys. Res. Lett.</i> , 34, L22707, doi:10.1029/2007GL031781.
17. Mann, M. E., Emanuel, K. A., Holland, G. J. & Webster, P. J., 2007: Atlantic TCs revisited. <i>EOS</i> , 88, 349–350.
18. Mann, M.E., Woodruff, J.D., Donnelly, J.P. and Zhang, Z., 2009: Atlantic hurricanes and climate over the past 1,500 years. <i>Nature</i> , 460, 880-885, doi:10.1038/nature08219.
19. Mooney, C., 2007: Storm World: Hurricanes, politics, and the battle over global warming. Harcourt, Inc., 392 pp. (This book won a special AMS award).
20. Santer, B.D. et al., 2006: Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. <i>Proceedings of the National Academy of Sciences</i> , 103, 13905-13910, 10.1073/pnas.0602861103.
21. Srivler, R. and M. Huber, 2006: Low frequency variability in globally integrated TC power dissipation. <i>Geophys. Res. Lett.</i> , 33, L11705, doi:10.1029/2006GL026167.
22. Trenberth, K. E., 2005: Uncertainty in Hurricanes and Global Warming. <i>Science</i> , 308, 1753-1754.
23. Trenberth, K. E., and D. J. Shea, 2006: Atlantic hurricanes and natural variability in 2005, <i>Geophys. Res. Lett.</i> , 33, L12704, doi:10.1029/2006GL026894.
24. Trenberth, K.E., 2007: Warmer Oceans, Stronger Hurricanes. <i>Scientific American</i> , 44-51, July.
25. Webster, P.J., G.J. Holland, J.A. Curry, H.-R. Chang, 2005: Changes in TC number, duration and intensity in a warming environment. <i>Science</i> , 309 (5742): 1844-1846.
26. Webster, P.J., J.A. Curry, J. Liu, G.J. Holland, 2006: Response to comment on "Changes in TC number, duration, and intensity in a warming environment". <i>Science</i> , 311 (5768):doi:10.1126/science.1121564.

Most of these papers were directed toward making the case for the likely influence of rising levels of CO<sub>2</sub> causing global SST increases and how these SST increases were making hurricanes more frequent or more intense. Authors stratified and manipulated their data and quoted other similarly directed papers in ways as to show and play up SST rising influence on enhanced hurricane activity. The wild and exaggerated media coverage during and after the 2004-2005 seasons helped condition the public to accept the possibility of a significant rising CO<sub>2</sub> influence on hurricanes.

The next section discusses some of the most erroneous statements and results which came forth from some of our country's most prominent and credentialed scientists and meteorologists. Few of these individuals however, had much real world background experience in the physics of how TCs behave.

#### **4. SUMMARY OF SOME OF THE ERRONEOUS AND OUTRAGEOUS STATEMENTS WHICH SET THE BACKGROUND TONE FOR THE IPCC-AR4 STATEMENTS ON TCs**

Brief summaries of the following papers demonstrate the extent to which various researchers went to quickly capture media attention and government funding by arranging their data sets and theories so as to ride the AGW – hurricane bandwagon. Most of these papers should never have made it through the review process to publication. These papers lacked accuracy and were grossly biased toward a rising CO<sub>2</sub> influence on global SSTs and TCs.

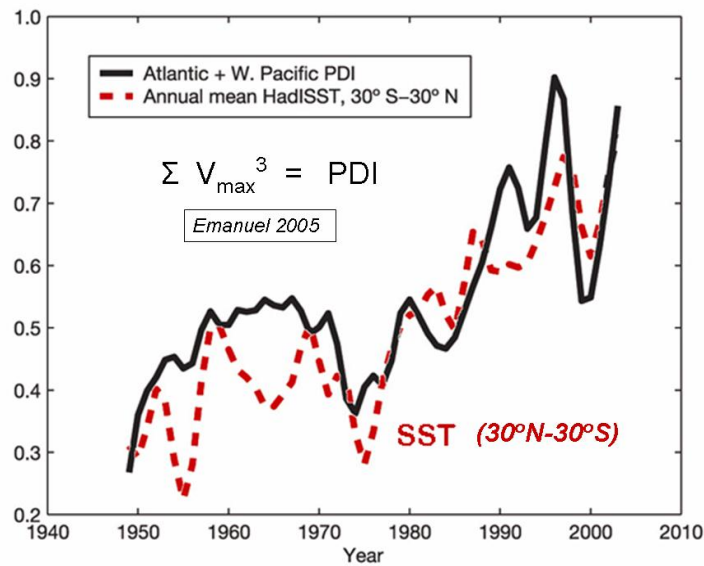
Two very short papers were published near the height of the 2005 hurricane season and stood above all the other papers in receiving unusual amounts of publicity, extensive references in journal literature, and in forming the basis for the IPCC-AR4 (2007) report on TCs.

These two papers were:

- a. Emanuel, K., 4 August 2005: Increasing destructiveness of TCs over the past 30 years. *Nature*, **436**, 686-688, and
- b. P. Webster, G. Holland, J. Curry and H-C. Chang, 16 September 2005: Changes in TC number, duration, and intensity in a warming environment. *Science*, **309**, 1844-1846.

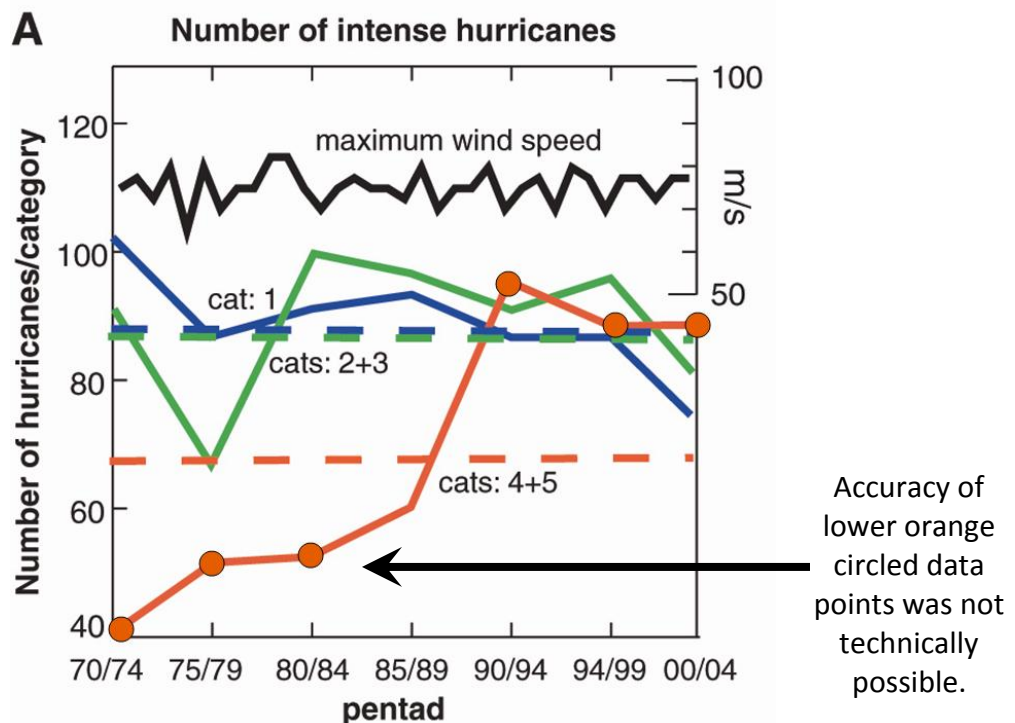
These two papers were published right before and just after the landfall of the very destructive Hurricane Katrina.

The first paper by K. Emanuel said that the frictional Power Dissipation Index (PDI) by hurricanes-typhoons had nearly doubled in the past 30 years in the North Atlantic and western North Pacific. He found that this increasing PDI (related to the cube of the cyclone's maximum wind,  $V_{\max}$ ) was highly correlated with rising tropical (30°N-30°S; 0-360°) SSTs. It was implied that future CO<sub>2</sub> increases would induce further tropical SST increases and that these increases would lead to future increases in TC destruction. He summarized his result in the figure below.



**FIGURE NOT TRUE – DATA USED WAS NOT RELIABLE AND CLOSENESS OF CURVES UNBELIEVABLE – AND NOT FOUND WITH OTHER DATA SETS**

The second paper by Webster, et al. said that the average number of the globe's most intense TCs (Category 4 and 5 hurricanes) had nearly doubled over the past 35 years. The authors did not realize that TC observation techniques in many of the globe's TC warning centers prior to the late 1980s were inadequate to successfully differentiate between Category 2-3 and Category 4-5 TCs. The following figure summarizes the primary results.



**FIRST HALF OF ORANGE CAT. 4-5 CURVE (DATA) NOT REALISTIC**

These two papers had fundamental observational and conceptual errors. Neither of them should have gotten through the peer-review process. I gave extensive media criticism of these papers at the time of their publication and wrote critical rebuttal letters to the editors of *Nature* and *Science*. Both of my rebuttal letters were rejected, and the authors ignored my criticisms. The authors accused me of directing ad-hominem attacks against them. Copies of these two papers and my unpublished rebuttal comments are attached as Appendix A. Being known to the US public through my over two-decades of Atlantic seasonal hurricane forecasts the media approached me for comments to these papers. I felt I had an obligation to try to set the record straight.

***Author's summary comments on the Emanuel paper.*** The operational methodology for determining a TC's maximum wind ( $V_{\max}$ ) from aircraft and satellite has not been very reliable and has varied over the decades. Taking the cube of such an unreliable  $V_{\max}$  measurement is certain to introduce greater uncertainty and larger up-and-down swings in any cumulative index. A TC's maximum winds are usually not well related to its outer radius wind strength and the cyclone's net frictional dissipation let alone the cube of an estimated maximum wind speed. See my discussion and full rebuttal in Appendix A.

In a study of the outer radius closed circulation of hurricanes and typhoons versus their inner-core intensity Merrill (1984) found a correlation of only 0.3, explaining only 10 percent of the variance. The same correlation was found by Merrill in his analysis of cyclone inner and outer core kinetic energy. Weatherford and Gray, 1988 (I and II) also found very small correlation between a typhoon's  $V_{\max}$  and its outer 1-2.5° radius tangential wind. The recent analysis by R. Maue (Figure 2.1) shows no such increases in ACE ( $V_{\max}$ )<sup>2</sup> to match Emanuel's increase in ( $V_{\max}$ )<sup>3</sup>.

***Author's summary comments on Webster-Holland-Curry-Chang paper.*** This figure's tabulations of the global number of Cat. 4-5 hurricanes during the 1970s and much of the 1980s could not have been accurate. Early year intense hurricane numbers were underestimated in all the global storm basins except the Atlantic. It was impossible to reliably distinguish Cat. 4-5 hurricanes from weaker Cat. 2-3 hurricanes during the first half of their measured period.

I conducted a UN-WMO sponsor survey trip of all 28 global TC centers in 1978-79. Most of the non-US centers did not have operational and reliable satellite equipment to distinguish Cat. 4-5 cyclones from the weaker Cat. 2-3 TCs. Most of the non-US hurricane forecasters had yet to be trained on use of the new GMS satellite instruments. The Japanese JMS satellite was not launched until December 1977. Many of the 1970s and 1980s Cat. 4-5 TCs were just not reported. This paper's assertions of a doubling of Cat. 4-5 hurricanes between the 1970s – early 1980s and 1986-2004 could not have possibly been realistic. The authors also had no physical justification for such a bold assertion of the doubling of these most intense cyclone systems. They further compounded their observation errors by implying that CO<sub>2</sub> increases (equivalent to about a ~0.3 Wm<sup>-2</sup> radiation differences between their two periods) were likely responsible for such large Cat. 4-5 increases. How reasonable is it to assume that such a small relative CO<sub>2</sub> induced energy component change would be able to cause up to a doubling of the globe's most intense Cat. 4-5 hurricanes? The globe has an average balancing in-and-out

radiation flux of about  $342 \text{ Wm}^{-2}$  – a thousand times the  $\text{CO}_2$  difference of their two 17-year before and after periods.

When the authors' were told by me of the lack of accuracy of their earlier category 4-5 TC numbers and their flawed physical theory, they refused to back down on the accuracy of their data. Their main response was to attack me for criticisms of their papers (see Appendix A and C for more background information) and acted with other scientists (of their persuasion) to see that I was not allowed to participate in three scientific panels that were debating this topic. For two years following the publication of their papers Webster, Holland and Curry fought hard via the internet with blog statements, talks and panel discussions to convince their colleagues of the validity of their results.

**Other Published Statements.** To illustrate a sampling of some of the erroneous and exaggerated statements that came forth on this topic during the 2005-2008 period, I will now quote some of the published statements which were made by some of the papers listed in Table 3.1. My comments on these statements are given in red.

**1. Emanuel Replies (2005) to Pielke and Landsea on their letter to editor concerning his *Nature* paper.**

Replying to: R.A. Pielke *Nature* **438**, doi:10.1038/nature04426(2005) and C.W. Landsea *Nature* **438**, doi:10.1038/nature04477(2005) Letters to the Editors comments. Emanuel makes the following statement:

"This count is highly correlated with both tropical Atlantic SST and Northern Hemispheric mean surface temperature through the entire record, casting doubt on whether the recent multi-decadal variability in tropical SST and hurricane activity is due purely to natural causes, as Landsea implies."

Also in Emanuel's rebuttal: "I MAINTAIN THAT CURRENT LEVELS OF TROPICAL STORMINESS ARE UNPRECEDENTED IN THE HISTORICAL RECORD AND THAT A GLOBAL WARMING SIGNAL IS NOW EMERGING IN RECORDS OF HURRICANE ACTIVITY."

**(A MAJORITY OF MY TC COLLEAGUES AND I DO NOT OBSERVE ANY SUCH EMERGING SIGNAL)  
In fact, Maue (2010) and Klotzbach (2006) observed a steady decrease in global TC activity over the last 20-30 years (see Figures 2.1 and 2.2).**

---

**2. M.E. Mann and K.A. Emanuel: Global Warming, the AMO, and North Atlantic TCs, *EOS*, 87, 13 June 2006.**

Key Statements: "A formal statistical analysis that separates human influences from possible natural cyclic influences indicates that human-induced factors are primarily responsible for the long-term trend in tropical Atlantic warmth and hurricane activity. The Atlantic Multidecadal

Oscillation (AMO), which has been hypothesized by some to strongly influence Atlantic hurricanes trends, was found to have no apparent role in the observed trend."

"We now know that the intensity of hurricanes has increased strongly over the past 30 years and is closely correlated with the rise in sea surface temperature during that period. Globally, the strongest hurricanes (category 4 and 5) have nearly doubled in frequency over the past 35 years."

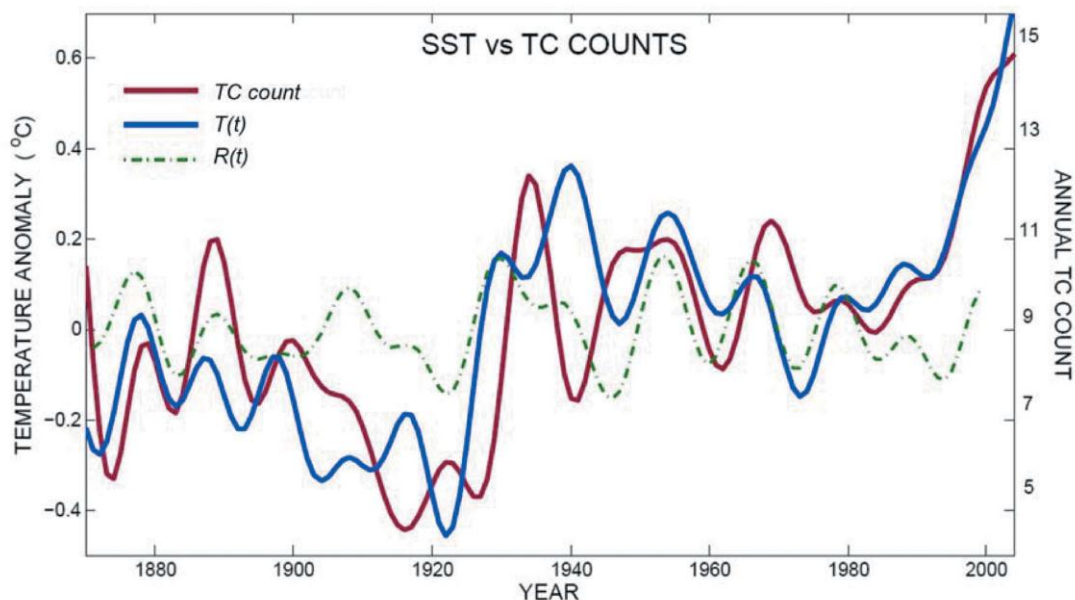
"... indicates that the overall trend and more than half of the total decadal variance in annual TC counts can be resolved by SST variations..."

"In other words, the SST variability underlying increased Atlantic TC activity appears unrelated to the AMO."

"It might be argued that other factors potentially associated with the AMO (e.g., changes in vertical wind shear in the tropical North Atlantic) could be responsible for the observed TC changes [e.g., *Goldenberg et al.*, 2001]. This possibility was rejected ..."

"Thus, it can be inferred that any factors unrelated to SST that might influence TC activity also do not exhibit any detectable multi-decadal cycles."

**(NOTHING COULD BE FURTHER FROM WHAT THE OBSERVATIONS INDICATE THAN WHAT THE AUTHOR'S UNDERLINED STATEMENTS SAY)**



*Comparison of decadal smoothed TC numbers with decadal smoothed ASO MDR SST series  $T(t)$  and decadal smoothed bivariate regression residual series  $R(t)$ . BAMS, 2006, 87, 1025.*

**(OBSERVATIONS ARE NOT RELIABLE ENOUGH TO SHOW SUCH A CLOSE ASSOCIATION BETWEEN SST AND TCs – TROPICAL CYCLONE NUMBERS DURING THE LATE 19<sup>TH</sup> AND EARLY 20<sup>TH</sup> CENTURY WERE UNDER-ESTIMATED)**

**3. Phil. Trans. R. Soc. A, doi:10.1098/rsta.2007.2083, Published online (2007).**

Heightened TC activity in the North Atlantic: natural variability or climate trend?

BY GREG J. HOLLAND AND PETER J. WEBSTER

“We have cited substantial work from other studies that conclude that anthropogenically-produced greenhouse gases have contributed to this trend throughout the entire period, and that their effect has accelerated since 1970 (e.g. Santer et al. 2006). In particular, global change due to greenhouse warming is responsible for around two-thirds of the current record high Atlantic SSTs.”

“In conclusion, the observed eastern Atlantic SST changes are driven by a combination of natural variability and anthropogenic effects, with the greenhouse warming (partially offset by cooling from sulphate gases) being the dominant process.”

“... we are led to the confident conclusion that the recent upsurge in TC frequency is due in part to greenhouse warming, and this is most likely the dominant effect. Earlier variations, such as the sharp increase in the 1930s, were also probably impacted by greenhouse warming.”

“But the combination of this oscillation with the increasing number of TCs also results in a strong trend in major hurricane numbers that is directly associated with greenhouse warming. These conclusions are robust to known errors in the available data.”

**(ALL UNDERLINED STATEMENTS ARE NOT TRUE) – The sheer arrogance of such wild and outlandish statements is an example of how far some TC authors were prepared to push their AGW-driven agenda.**

---

**4. Mixing Politics and Science in Testing the Hypothesis That Greenhouse Warming Is Causing a Global Increase in Hurricane Intensity**

BY J. A. CURRY, P. J. WEBSTER, AND G. J. HOLLAND  
BAMS, 2006, **87**, 1025

“We presented an analysis of the scientific issues surrounding the Emanuel (2005) and WHCC papers in a manner designed to identify the most important critiques and focus the scientific debate. We formulated the central hypothesis that greenhouse warming is causing an increase in hurricane intensity as a causal chain consisting of three subhypotheses that are individually and collectively more easily evaluated than the central hypothesis. Assessing each of these subhypotheses against logically valid critiques has clarified the support for the hypotheses and the outstanding uncertainties.”

**(STATEMENTS ARE NOT BELIEVABLE)**

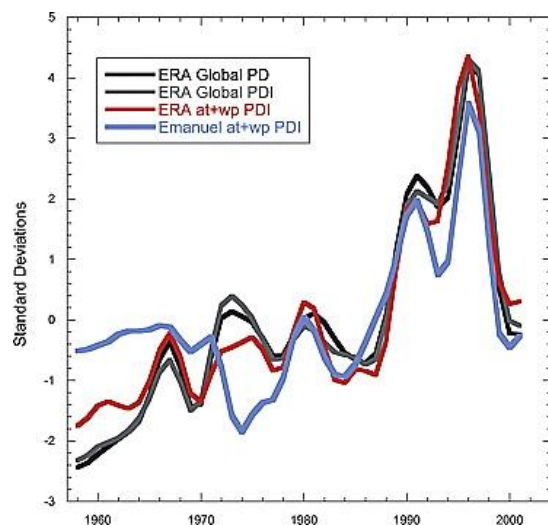
5. J.B. Elsner, Evidence in support of the climate change-Atlantic hurricane hypothesis, *Geophysical Research Letters*, 23 August 2006.

Key Finding: This study finds that the increase in air temperature due to global warming is causing the increase in sea surface temperature, providing additional evidence that human-induced climate change is leading to increased Atlantic hurricane activity. **(NOT TRUE – We find no such evidence)**

No reference to or discussion of the primary role of the North Atlantic Ocean thermohaline circulation (THC) in causing such strong multi-decadal variations in Atlantic major hurricane activity.

6. R. Sriver and M. Huber, Low frequency variability in globally integrated TC power dissipation, *Geophysical Research Letters*, 8 June 2006.

Key Finding: This analysis found a strong upward trend in power dissipation, showing good agreement with Emanuel (2005) after 1978. The power dissipation trend closely correlates with average annual tropical temperature, adding to the evidence that tropical temperatures directly regulate the intensity of TCs.



**(EARLY-PERIOD DATA ARE NOT RELIABLE ENOUGH TO ASSOCIATE PDI AND SST. HOW IS IT POSSIBLE FOR SST AND PDI TO BE IN SUCH CLOSE AGREEMENT? – A DIRECT COPY OF EMANUEL)**

7. K.E. Trenberth and D.J. Shea, Atlantic hurricanes and natural variability in 2005, *Geophysical Research Letters*, 27 June 2006.

Key Finding: Sea surface temperature in the tropical North Atlantic region are critical for hurricanes. This analysis deconvolves the major factors contributing to this high temperature and finds that global warming was responsible for most of the record high temperature.

**(NOT TRUE – AUTHORS APPEAR NOT TO KNOW ABOUT THE ATLANTIC OCEAN THERMOHALINE CIRCULATION (THC) – THE MAIN DRIVER FOR NORTH ATLANTIC SST VARIATIONS AND OF MAJOR ATLANTIC HURRICANE VARIABILITY)**

8. B.D. Santer, *et al.* (16 co-authors), **Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions**, Proceedings of the National Academy of Sciences, 5 September 2006.

Key Finding: This study used 22 climate models to determine the causes of the increase in sea surface temperature in the tropical Atlantic and Pacific regions where hurricanes develop. The findings suggest that the observed rise in temperature cannot be due solely to natural climate variations and that the human-induced increase in greenhouse gases is the most potent driver of the observed temperature increases in the key hurricane formation zones, responsible for about two-thirds of the ocean warming in these key regions.

**(HOW ARE THESE AUTHORS ABLE TO SEPARATE THE INFLUENCE OF HUMANS FROM NATURE? HOW DO THEY KNOW WHAT THE REST OF US WHO HAVE BEEN STUDYING HURRICANES FOR DECADES DO NOT KNOW? – WHY TWO-THIRDS AND NOT HALF OR 90 PERCENT FOR THE HUMAN INFLUENCE ON SST?)**

---

9. C.D. Hoyos, P.A. Agudelo, P.J. Webster, J.A. Curry, **Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity**, *Science*, 7 April 2006.

Key Finding: The trend of increasing numbers of category 4 and 5 hurricanes is directly and primarily related to the trend in sea surface temperature. Other aspects of the tropical environment do not contribute substantially to the observed upward global trend. These findings refute the notion that wind shear and these other factors are primary drivers of hurricane intensity, on a par with sea surface temperature.

**(AUTHORS ONLY DISPLAY THEIR IGNORANCE WITH SUCH UNTRUE STATEMENTS – A DIRECT COPY OF OTHER AUTHORS)**

---

10. K.E. Trenberth, **Warmer Oceans, Stronger Hurricanes**, *Scientific American*, July 2007, 44-51. In this article's summary Trenberth makes the following statements.

"Trouble to Come: Both observations and theory therefore suggest that hurricanes are becoming more intense as the earth warms." ...

"... so it is possible or even likely that fewer cyclones might form, with those that do arise being larger and more intense." ...

"As we continue to improve our models and observations, we all would be wise to plan for more extreme hurricane threats."

**(HOW DOES HE KNOW THIS? – TRENBERTH CAN'T BACK UP THESE STATEMENTS WITH DATA OR PLAUSIBLE THEORY) – HE HAS VERY LITTLE BACKGROUND IN TC STUDY.**

Trenberth's *Scientific American* 2007 paper lists only four references to individuals who agree with him. This article could not have been peer reviewed and should be a major embarrassment to *Scientific American*. Listed below are the four referenced articles. One to himself, one to Emanuel, and the other two to the discredited Emanuel and Webster et al. papers.

1. Divine Wind: The History and Science of Hurricanes. Kerry Emanuel. Oxford University Press. 2005.
2. Increasing Destructiveness of TCs over the Past 30 Years. Kerry Emanuel in *Nature*, Vol. 436, pages 686-688; August 4, 2005.
3. Changes in TC Number, Duration and Intensity in a Warming Environment. P.J. Webster, G.J. Holland, J.A. Curry, and H.R. Chang in *Science*, Vol. 309, pages 1844-1846; September 16, 2005.
4. Atlantic Hurricanes and Natural Variability in 2005. Kevin E. Trenberth and Dennis J. Shea in *Geophysical Research Letters*, Vol. 33, No. 12; June 2006.

**(THIS PAPER WAS PURE AGW PROPAGANDA – WITHOUT ANY BASIS IN REALITY)**

---

11. TRENBERTH'S AGW ADVOCACY. As the first listed primary author of the IPCC-AR4 Report – Chapter 3, Kevin Trenberth showed no reluctance to publish the above one-sided (and incorrect) article explaining his strong and biased views that global warming (from CO<sub>2</sub> rises) is making hurricanes more intense.

Trenberth had been aware that many of us in the TC community were strongly at odds with his viewpoint that increases in CO<sub>2</sub> have any significant influence on global TC activity. But he chose to have the IPCC-AR4 chapter he was responsible for ignore all of our many opposite opinions.

Trenberth is a climate scientist, not a TC specialist. Yet only the viewpoints of his small group of warming colleagues went into the TC section of the IPCC-AR4 report. There is no question that Trenberth was intending to edit Chapter 3 in such a way as to say that CO<sub>2</sub> increases were having a strong influence on hurricane activity. The other primary editor of this IPCC-AR4 – Chapter 3, Phil Jones, has recently encountered charges of irregularity in his handling of University of East Anglia meteorology data from the hacked e-mails associated with Climategate.

The global meteorological community would be hard pressed to find two individuals who were more dogmatic in their belief of the influence of rising levels of CO<sub>2</sub> on increases in global temperature and TC activity.

Trenberth had earlier pushed for public acceptance of the belief that hurricanes were getting worse due to rises in CO<sub>2</sub> by organizing a US panel of prominent scientists (none of whom had any background knowledge of TCs or even background in meteorology or climatology – most were medical doctors) to proclaim that the very destructive Atlantic hurricane seasons of 2004-

2005 were evidence of a human influence on TCs. This was an obvious propaganda ploy by Trenberth without any scientific basis.

Dr. Chris Landsea, of the NOAA National Hurricane Center, the only real TC specialist on the IPCC-AR4 panel was so turned off by Trenberth's quite obvious propaganda ploy that he felt obliged to resign from the IPCC-AR4 team in early 2006 ([see Appendix B for Landsea's letter explaining his decision to resign](#)). Landsea's resignation left the door wide open for those other IPCC panel members (without TC background) to be able to write the portion of Chapter 3 in which they could emphasize the (by then discredited) papers of Emanuel (2005), Webster et al. (2005) and some of the other papers of Table 3.1.

---

12. In September 2007 Trenberth wrote a short Op/Ed comment for EOS, which said:

**"Clarity Emerging on Hurricanes?"**

The situation on how hurricanes have changed and will likely change in the future are outlined in my recent *Scientific American* article, but may seem as murky as ever to the public although clarity is actually emerging.

"A recent news report in the Press Register outlines some sources of confusion related to just how well the past record is known. It cites work by Landsea that relied on numbers of land-falling storms as a way to calibrate the Atlantic hurricane record, and which concluded that there may be an undercount of 3.2 storms per year prior to 1966. The most recent *Eos Transactions* has two articles that follow up and point out why use of land-falling storms is misleading [Holland 2007; *Eos* 88 (36) 348-349] and that the conclusions of increased activity do not change anyway [Mann et al., 2007; *Eos* 88 (36)]. "

"The Holland article points out that there are good reasons why the fraction of storms making landfall should change, both because of natural variations and especially if the climate changes. The Mann et al. article adopts the Landsea-suggested changes for the past as a "what if" test and goes on to show that even a substantial underestimate of early 20th century storms does not change the significance of the increase in activity since 1994. Nor does it change the strong relationship with observed sea surface temperatures (SSTs) in the region; the SSTs have a much more reliable observational record and have clearly increased."

"Surprisingly, none of these studies refers to what seems to me to be the most definitive analysis of the likely missed storms in the historical counts by Chang and Guo (2007) in which they analyze in detail the actual ship tracks in the past compared with modern tropical storm tracks. To quote their main conclusions: "It is estimated that the number of tropical cyclones not making landfall over any continent or the Caribbean may have been underestimated by up to 2.1 per year during 1904–1913, with this number decreasing to 1.0 per year or less during the 1920s and later decades. Our results suggest that the

characteristics of North Atlantic tropical cyclone track statistics might have changed during the 20th century.”

“In 2007 the tropical storm season has been fairly normal in many respects up to now. Only 3 hurricanes have been recorded (versus average 3 to 4) but two were category 5 storms, and that is highly unusual. Forecasts of hurricane activity by NOAA and Bill Gray continue to forecast substantially above normal activity in the Atlantic. To me, observing the events thus far, the incredibly intense convective activity in the Indian Ocean from May to July was an important and totally overlooked factor. The subsequent heavy rains and flooding in India and China were no doubt related. The fact that Atlantic hurricane activity is influenced by events in the Indian Ocean seems to be overlooked by the hurricane forecasters.”

### **I WROTE A RESPONSE TO TRENBERTH’S ASSERTIONS OF CLARITY EMERGING ON HURRICANES – IT IS AS FOLLOWS:**

“Trenberth’s central theme of emerging clarity on hurricane and climate change is, in my view, totally bogus as was his *Scientific American* (SA) article of July 2007 saying how hurricanes will change in the future. His SA article was very one sided and factually wrong in many places. It could not have been peer reviewed.

There is absolutely no clarity emerging on the question of human influence on hurricanes and hurricane changes associated with climate change. This dichotomy between the group of researchers saying that humans are likely influencing hurricanes (Trenberth is of this group) and the many others of us saying there is no solid evidence or physical basis for such a linkage is widening, not converging. Most of those believing that humans are affecting hurricanes have a vested interest that their views be accepted. Most of us skeptics do not.

The papers Trenberth cites in his Op/Ed as backing a growing clarity on this topic have major flaws and are not accepted by most of us who are skeptical of significant human influences on hurricanes. There is no reliable evidence that Atlantic basin (or global) hurricane activity shows changes over the last century beyond the changes in the Atlantic brought about by the oscillating Atlantic Ocean THC which is driven by salinity changes. United States landfalling hurricane numbers (the most reliable long-term data we have) show a decrease over the last century. This is particularly noticeable in US landfalling major (Cat 3-4-5) hurricanes. How could anyone honestly conclude that long-term Atlantic hurricane activity is increasing or that clarity was emerging on this topic?”

**EOS did not accept this rebuttal statement.**

**SUMMARY. Perhaps I should not have been so surprised that so many individuals would bend their objectivity in order to join in an exploding bandwagon movement (i.e. AGW) that appeared in 2005-2008 to have such big future rewards attached with it. But surprised I was – to the core!**

## 5. THE IPCC-AR4'S AUTHORS OF CHAPTER 3 WHICH DISCUSSED TROPICAL CYCLONES – TAKEN DIRECTLY FROM THIS REPORT – **GRAY COMMENTS IN BLUE**

### 3. Observations: Surface and Atmospheric Climate Change

#### Coordinating Lead Authors:

Kevin E. Trenberth (USA), Philip D. Jones (UK)

#### Lead Authors:

Peter Ambenje (Kenya), Roxana Bojariu (Romania), David Easterling (USA), Albert Klein Tank (Netherlands), David Parker (UK), Fatemeh, Rahimzadeh (Iran), James A. Renwick (New Zealand), Matilde Rusticucci (Argentina), Brian Soden (USA), Panmao Zhai (China)

#### Contributing Authors:

R. Adler (USA), L. Alexander (UK, Australia, Ireland), H. Alexandersson (Sweden), R. Allan (UK), M.P. Baldwin (USA), M. Beniston (Switzerland), D. Bromwich (USA), I. Camilloni (Argentina), C. Cassou (France), D.R. Cayan (USA), E.K.M. Chang (USA), J. Christy (USA), A. Dai (USA), C. Deser (USA), N. Dotzek (Germany), J. Fasullo (USA), R. Fogt (USA), C. Folland (UK), P. Forster (UK), M. Free (USA), C. Frei (Switzerland), B. Gleason (USA), J. Grieser (Germany), P. Groisman (USA, Russian Federation), S. Gulev (Russian Federation), J. Hurrell (USA), M. Ishii (Japan), S. Josey (UK), P. Kållberg (ECMWF), J. Kennedy (UK), G. Kiladis (USA), R. Kripalani (India), K. Kunkel (USA), C.-Y. Lam (China), J. Lanzante (USA), J. Lawrimore (USA), D. Levinson (USA), B. Liepert (USA), G. Marshall (UK), C. Mears (USA), P. Mote (USA), H. Nakamura (Japan), N. Nicholls (Australia), J. Norris (USA), T. Oki (Japan), F.R. Robertson (USA), K. Rosenlof (USA), F.H. Semazzi (USA), D. Shea (USA), J.M. Shepherd (USA), T.G. Shepherd (Canada), S. Sherwood (USA), P. Siegmund (Netherlands), I. Simmonds (Australia), A. Simmons (ECMWF, UK), C. Thorncroft (USA, UK), P. Thorne (UK), S. Uppala (ECMWF), R. Vose (USA), B. Wang (USA), S. Warren (USA), R. Washington (UK, South Africa), M. Wheeler (Australia), B. Wielicki (USA), T. Wong (USA), D. Wuertz (USA)

#### Review Editors:

Brian J. Hoskins (UK), Thomas R. Karl (USA), Bubu Jallow (The Gambia)

#### This chapter should be cited as:

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

**Gray Comment** – I recognize no real long-term tropical cyclone specialists among this large group of listed Chapter 3 authors and reviewers.

## ERRONEOUS STATEMENTS CONCERNING TCs WHICH ARE CONTAINED IN THE IPCC-AR4.

### 1. Portion of IPCC-AR4 which states (page 239)

*"Intense TC activity has increased since about 1970. ...Globally, estimates of the potential destructiveness of hurricanes show a significant upward trend since the mid-1970s, with a trend towards longer lifetimes and greater storm intensity, and such trends are strongly correlated with tropical SST. These relationships have been reinforced by findings of a large increase in numbers and proportion of hurricanes reaching categories 4 and 5 globally since 1970 even as total number of cyclones and cyclone days decreased slightly in most basins. The largest increase was in the North Pacific, Indian and southwest Pacific Oceans."*

**Gray Rebuttal** – There is absolutely no reliable observational data or plausible theoretical basis that agrees with the above IPCC-AR4 statement that category 4-5 TCs have become more frequent since 1970.

### 2. IPCC-AR4 page 308

*"Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s."* – and:

*"These relationships have been reinforced by findings of a large increase in numbers and proportion of strong hurricanes globally since 1970 even as total numbers of cyclones and cyclone days decreased slightly in most basins. Specifically, the number of category 4 and 5 hurricanes increased by about 75% since 1970."*

**Gray Rebuttal** – These statements were taken directly from the discredited work of the Emanuel (2005) and Webster et al. (2005) papers – and some of the many cited papers of Table 3.1. The gross observation and theoretical errors of these reports were well known by most serious TC researchers and forecasters before the IPCC-AR4 was finalized in 2007. Yet they became part of the IPCC-AR4 Summary.

### 3. IPCC-AR4 pages 304-305 states

*"The Power Dissipation Index (PDI) of the total power dissipation for the North Atlantic and western North Pacific (Emanuel, 2005a) showed substantial upward trends beginning in the mid-1970s. Because the index depends on wind speed cubed, it is very sensitive to data quality, and the initial Emanuel (2005a) report has been revised to show the PDI increasing by about 75% (vs. about 100%) since the 1970s (Emanuel, 2005b). The increase comes about because of longer storm lifetimes and greater storm intensity, and the index is strongly correlated with tropical SST. These relationships have been reinforced by Webster et al. (2005, 2006) who found a large increase in numbers and proportion of hurricanes reaching categories 4 and 5 globally since 1970 .... The largest increase was in the North Pacific, Indian and Southwest Pacific Oceans. These studies have been challenged by several scientists (e.g., Landsea, 2005; Chan, 2006) who*

*have questioned the quality of the data and the start date of the 1970s. .... In particular, in the satellite era after about 1970, the trends found by Emanuel (2005a) and Webster et al. (2005) appear to be robust in strong association with higher SSTs (Emanuel, 2005b)."*

**Gray Rebuttal** – As previously discussed this long summary paragraph is way off base. This statement leaves no question that the TC portion of the IPCC-AR4 report relied primarily on the discredited Emanuel and Webster et al. papers discussed in section 4, even though much superior information was available and could have been included in the IPCC-AR4 Report.

4. IPCC-AR4 page 305

*"As the climate changes and SSTs continue to increase, the environment in which tropical storms form is changed. Higher SSTs are generally accompanied by increased water vapour in the lower troposphere, thus the moist static energy that fuels convection and thunderstorms is also increased."*

**Gray Rebuttal** – The above statement has little validity. All the IPCC-AR4 statements imply that hurricane intensity is strongly and directly related primarily only to SST increases under the assumption that as SST increases so does lapse-rate buoyancy and TC increase. This is not true on a climate time scale – see the extensive discussion of the lack of an association between global SST, lapse-rate buoyancy, and TC activity (sections 9-14).

5. IPCC-AR4 page 786

*"Earlier studies assessed in the TAR showed that future TCs would likely become more severe with greater wind speeds and more intense precipitation. More recent modeling experiments have addressed possible changes in TCs in a warmer climate and generally confirmed those earlier results."*

and, IPCC-AR4 page 788:

*"Higher resolution models that more credibly simulate TCs project some consistent increase in peak wind intensities...."*

**Gray Rebuttal** – These statements are speculative. Reliable (i.e. skillful) climate modeling of long-period future TC activity is not possible, and due to the complex and chaotic nature of the global climate system may never be possible.

The organizers of the IPCC-AR4 report were biased from the start in wanting this report to say that global TCs were getting more intense and more frequent due to rising levels of CO<sub>2</sub>. They referenced only the papers which agreed with their erroneous perceptions. They completely ignored the overwhelming opinions of those more experienced TC researchers and forecasters who thought otherwise.

**SUMMARY.** From the vigorous defense of the authenticity of their papers that Emanuel, Webster, Holland, Curry, Trenberth, Santer, and Mann have long maintained, it appears that these authors may feel that they are too committed to their faulty data and ideas to back down despite what the observations indicate. I have yet to hear any of them admit that they were wrong or that their results were much too exaggerated.

I have never before seen such a blatant cherry-picking of observations which support an ideological point-of-view and the complete ignoring of data of the opposite persuasion. (The Climategate e-mails on publication editor selection and attempted control of papers might offer a partial explanation).

The accuracy of these authors' papers listed in Table 3.1 have not been accepted by the majority of the experienced TC forecasters with which I have discussed their results. The voluminous material and discussion contained in our Colorado State University seasonal hurricane reports (issued 2-4 times annually for the last 28 years), the material available on the National Hurricane Center's and Joint Typhoon Warning Center's websites, the material emanating from Professor Johnny Chan at City University of Hong Kong on Pacific TC climatology, and many other reports and statements on this topic from experienced TC specialists were completely ignored by the IPCC.

## **6. IGNORING THE UN-WMO TC WORKSHOP OF 2006**

Why did the IPCC-AR4 report choose to ignore the climate-TC statements coming out of the UN-WMO sponsored 6<sup>th</sup> International Workshop on TCs (IWTC) in November 2006 in Costa Rica? I attended this workshop. The question of potential anthropogenic influences on global TC activity was given extensive discussion. Table 6.1 lists the workshop's summary statements on this topic.

The summary of this workshop on anthropogenic influences on TC activity was anything but decisive. Note how hesitant this international workshop (containing many of the best of the world's TC forecasters and researchers) was to endorse anything like the type of statements which later came forth from the IPCC-AR4 report. This workshop noted the great problems and impossibility of determining if rising levels of CO<sub>2</sub> would have a detectable influence on global TC activity. The IPCC-AR4 chose to ignore the workshop's statements.

I personally felt that the IWTC-VI was too tolerant of the possibility of anthropogenic influences on TCs. Many of the attendees appear to have believed much of the media-driven warming hype. Others did not have strong views one way or the other.

**Table 6.1** – Sixth UN-WMO International Workshop on TCs which was held in San Jose, Costa Rica in November 2006. The consensus summary of climate and anthropogenic influences on global TCs are listed below.

1. <u>Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point.</u>
2. No individual tropical cyclone can be directly attributed to climate change.
3. The recent increase in societal impact from tropical cyclones has largely been caused by rising concentrations of population and infrastructure in coastal regions.
4. Tropical cyclone wind speed monitoring has changed dramatically over the last few decades, leading to difficulties in determining accurate trends.
5. There is an observed multi-decadal variability of tropical cyclones in some regions whose causes, whether natural, anthropogenic or a combination, are currently being debated. This variability makes detecting any long-term trends in tropical cyclone activity difficult.
6. It is likely that some increase in tropical cyclone peak wind-speed and rainfall will occur if the climate continues to warm. Model studies and theory project a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures.
7. There is an inconsistency between the small changes in wind-speed projected by theory and modeling versus large changes reported by some observational studies.
8. Although recent climate model simulations project a decrease or no change in global tropical cyclone numbers in a warmer climate, there is low confidence in this projection. In addition, it is unknown how tropical cyclone tracks or areas of impact will change in the future.
9. Large regional variations exist in methods used to monitor tropical cyclones. Also, most regions have no measurements by instrumented aircraft. These significant limitations will continue to make detection of trends difficult.
10. If the projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclone storm surge flooding will increase.

## 7. MOONEY’S JUDGMENTS

Chris Mooney’s book *Storm World* (Harcourt, 392 pp) was published in 2007. It gives an excellent historical summary of the evolution of ideas concerning the physics of TCs and of the heated discussions between ‘believers’ and ‘skeptics’ of whether AGW might make hurricanes more frequent and damaging in coming years. The majority of his book covers the hurricane research and the personalities on both sides of these heated debates which occurred in the two years following the disastrous 2004-2005 seasons which saw 8 powerful hurricanes cross the US coastline. Mooney, a Yale University graduate (English major) and a professional writer started his full-time two-year research for this book right after the very damaging 2005 hurricane season. He had just finished publishing a NY Times best selling book titled *The Republican War on Science* (2005 - Perseus, 342 pp) which well demonstrated Mooney’s acceptance of a CO<sub>2</sub>

influence on global warming. This earlier book criticized the Bush administration and various US Congressional members about not accepting the science of AGW and for dragging their feet about passing legislation to reduce US CO<sub>2</sub> emissions.

Mooney ostensibly took on this new book writing assignment with the purpose of getting to the bottom of the question of whether increases in global temperature due to CO<sub>2</sub> (already accepted by him as occurring before he started) could also be extended to include a significant AGW influence on global TC activity, particularly hurricane activity in the Atlantic. In the book's prologue Mooney states,

"I worried in late 2005 that those charged with re-building New Orleans might be paying inadequate attention to the possibility of an even worse hurricane disaster at some point in the future ... evidence suggests we may be entering a world in which, thanks to human-induced global warming, the average hurricane itself becomes more powerful and deadly."

Mooney appears to have approached the writing of his book with a desire (perhaps unconscious) to find evidence that increasing levels of CO<sub>2</sub> were indeed going to make hurricanes more destructive. Although he thoroughly interviewed me on a number of occasions and a few other CO<sub>2</sub> skeptics like Chris Landsea, the majority of his discussions and the larger part of his book's citations were given to the known and well established 'believers' of CO<sub>2</sub> having a significant influence on elevating global temperature and on consequent enhancement of TC activity. Table 7.1 lists all of Mooney's page citations in his book's index. Six of the then best known advocates of CO<sub>2</sub>'s enhancement of TCs versus three of us who were skeptical of such an influence. Also listed are many page citations to the Geophysical Fluid Dynamics Laboratory (GFDL) – strong supporters of CO<sub>2</sub>-enhanced global warming and CO<sub>2</sub> enhancement of more intense hurricanes. He also cited global climate modeling whose practitioners who almost unanimously support a direct CO<sub>2</sub> and global warming linkage and the probability of a global warming – stronger TC association.

Mooney did not contact the many hundreds of other experienced meteorologists who are actually making daily weather forecasts. The majority of daily weather forecasters are skeptical of long range GCM predictions of global warming and stronger hurricanes because they see how difficult it is for the numerical models to consistently show forecast skill out to just 4-5 days let alone 50-100 years.

**Table 7.1** – Comparison of the number of page citations in Mooney’s (2007) book *Storm World* between proponents (or ‘believers’) of CO<sub>2</sub> affecting TCs and those who are skeptical of a significant linkage. Also, given are the numbers of citations to the GFDL modeling lab and to Global Climate Models (GCMs) in general.

BELIEVERS	SKEPTICS
K. Emanuel (101)	W. Gray (107)
P. Webster (52)	C. Landsea (57)
G. Holland (32)	M. Mayfield (15)
T. Knutson (30)	
J. Curry (27)	
K. Trenberth (26)	
<b>Total AGW-Proponents page citations (268)</b>	<b>Total Skeptic page citations (179)</b>
GFDL (34)	
Global climate models (GCMs) – (37)	
<b>GRAND TOTAL (337)</b>	<b>GRAND TOTAL (179)</b>

It is not surprising that such a large selection of references to ‘believers’ in AGW would lead him, in the end, to the conclusion he arrived at – “that we have to trust the consensus of researchers (not forecasters) that rising levels of CO<sub>2</sub> will indeed act to make future hurricanes more destructive”. He apparently did not take into account the degree to which most of the ‘believer’ researchers he consulted had a vested interest in the warming-TC scare. They were receiving grants from federal agencies whose directors had similar views as his. By contrast, most skeptics have been hard-pressed to obtain government grant support for their research. I have experienced major difficulties since my views on AGW became known over two decades ago.

Given Mooney’s already innate acceptance of CO<sub>2</sub>-induced global warming that he had going into his two year book preparation it was to be expected that he would come away with the conclusion he did. Arguments by C. Landsea, M. Mayfield, other skeptics and me could not dissuade Mooney from his desired conclusion that AGW was going to progressively have an ever-increasing influence on making TCs more destructive. Mooney concludes his book with the following two paragraphs:

“I couldn’t recommend his (Gray’s) view of the science of global warming to the public, or to the people in power who make decisions on behalf of us all. There’s just too much at stake, and too little support for Gray’s views among the broader scientific community. For despite Gray’s and Michael Crichton’s sneering at scientific ‘consensus’, it’s really all we have – we laypersons, we journalists, we politicians – to go on.”

“While these statements clearly depict a field of science that’s in flux, they also more than justify worry on the part of a journalist, a citizen, or a decision-maker. We don’t know yet the precise ‘hurricane sensitivity’ to climate change, but it could be very significant. By the time we successfully quantify it, we may already be well within its range. Perhaps we’re seeing hints of that sensitivity kick-in already in the form of spates of record-breaking storms. Perhaps we’re seeing it in the Atlantic. And even if we haven’t yet, we’re likely to in the coming years.”

Mooney is a very perceptive, vigorous and talented writer. He had, however, too much of a built-in bias at the start and did not have the scientific background to be able to grasp and judge the fundamental physical flaws in both the CO<sub>2</sub> linkage to global warming as well as the flaws in the global warming-TC linkage. Mooney wasn’t able to appreciate just how fundamental were the physical flaws in the global modeler’s cloud and water-vapor positive feedback assumptions, how albedo energy to space dominates over IR blockage in rain areas, or how fundamental the ocean’s Atlantic thermohaline circulation (AMO) and Antarctica’s bottom water formation (or combination) is to the understanding of the last century’s surface global SST changes.

Since he was not an active participant in research, he also could not fully appreciate the large self interest as well as the political machinations of the scientists and government officials who professed a belief in AGW as a positive lever for grant support, and for career maintenance and/or advancement. Mooney chose to rely on the consensus. He talked to people who would tell him what he (perhaps unknowingly) wanted to hear. The global warming question has never really been about science. It has been primarily about politics and scaring people to have them more willing to follow government directives and the questionable views of pro-world government and environmentalists who believe they know what is best for humanity.

This book was very insightful in presenting much of the back and forth debates on this topic during the period from 2005-2007. I would recommend it to anyone with an interest in this topic. But I do not recommend that anyone accept Mooney’s final conclusion. He lacked the scientific background knowledge and an unbiased view to be able to make a really objective decision on this complex topic. Perhaps aware of his own scientific limitations, he felt that he could not express his own views and thus decided to go with the consensus view of the GCM modelers.

Following *Storm World* (2007), Mooney co-authored another book with biologist Sheril Kirshenbaum titled *Unscientific America* (2009 - Perseus, 209 pp). This book, was in summary, a criticism of those scientists who did not follow the scientific consensus concerning the reality and the importance of AGW.

More recently Mooney has described AGW skeptics as anti-science. This is wrong. We are only anti-science for scientific statements which lack a firm basis in reality. Mooney was awarded a special American Meteorology Society (AMS) outstanding science book award for his authorship of *Storm World*. The book’s conclusions were in agreement with the current AMS’s upper echelon thinking on this topic. Had his book’s conclusion been opposite to the one he advanced I doubt that he would have received this award. The book appears to have been well received by the scientific community of which the majority are AGW proponents.

Mooney (a non-scientist) has recently been appointed to the governing board of the American Geophysical Union (AGU), a scientific society. His views on the consequences of CO<sub>2</sub> increases on AGW were undoubtedly a crucial component of his appointment. He is a very valuable propaganda tool for any scientific society who advocates a belief in human-induced global warming. It apparently does not matter to the AGU that Mooney is not a scientist and has no university training in geophysics. He writes and speaks intelligently in support of the consensus (erroneous) view where ‘real truth’ appears to have been assigned a lower rung than the desired ‘perception of truth’.

## 8. PRESTIGIOUS SCIENTISTS WHO HAVE ADVOCATED OR SUPPORTED AN INFLUENCE OF RISING LEVELS OF CO<sub>2</sub> ON TC ACTIVITY

Table 8.1 is a list of some of the important and prestigious scientists in the group of meteorologists-climatologists and modelers who have advocated or implied that there is a direct relationship between CO<sub>2</sub> rises and increases in TC intensity/frequency. Their papers, public statements, and behind the scenes machinations helped shape the background thinking for the topical cyclone statements of the IPCC-AR4 report and much media coverage following the 2004-05 hurricane seasons. Yet only four of them on the list (Anthes, Emanuel, Holland, and Knutson) have established careers in TC research, and only two from this group have ever made official real-time hurricane forecasts for any substantial period.

**Table 8.1** – Group of the prominent senior scientists and officials most active in advocating a CO<sub>2</sub> influence on TC activity.

Rick Anthes	Kerry Emanuel●●	Phil Jones	Ben Santer●
Tim Barnett	James Hansen	Michael Mann●	Gavin Schmidt
Robert Corell●	Isaac Held	Mike MacCracken	Kevin Trenberth●●
Judy Curry ●●	Greg Holland●●	Chris Mooney●	Peter Webster●●

- Most active in advocating a CO<sub>2</sub> influence on global TC activity.
- Five individuals most vocal and pro-active with the media. Ben Santer and Michael Mann might also be added to this special group.

These individuals appear to have had an inordinate influence with our federal research funding agencies (NSF, NOAA, NASA, DOE, etc.) to influence these agencies to fund grant proposals favoring the view of an increasing CO<sub>2</sub> influence on TC activity and to try to discourage funding and/or a public platform for those with opposing viewpoints.

Table 8.2 gives a truncated listing of the high positions held and outstanding background credentials of some of these leading proponents of a CO<sub>2</sub> influence on AGW and TCs. All (except one) have Ph.D. degrees on a science related topic. Most of them are between 50-70 years old with between 30-50 years of working experience in the meteorological, climatological, and climate modeling field.

**Table 8.2** – Most prominent and credentialed senior scientists who have professed a belief in CO<sub>2</sub> induced global warming and who have directly or indirectly have supported a significant relationship between rising levels of CO<sub>2</sub> and TC activity.

<p><b>RICK ANTHES</b> President of the University Corporation for Atmospheric Research (UCAR). Extensive background in TC modeling. Former President of the American Meteorological Society (AMS). AMS Charney Award and many other awards and recognitions of his many accomplishments and broad leadership in the atmospheric science field.</p>
<p><b>TIM BARNETT</b> Research Marine Geophysicist, Climate Research Division, Scripps Institution of Oceanography, University of California, San Diego, CA. AMS Sverdrup Gold Medal. Fellow of the AGU and AMS. Many citations to his research endeavors.</p>
<p><b>ROBERT CORELL</b> Senior government coordinator of a variety of activities associated with advocacy for the awareness and the recognition of human-induced global warming. Principal for the Global Environment &amp; Technology Foundation, and an Ambassador for ClimateWorks. Partner of the Sustainability Institute and its C-ROADS Climate Interactive Initiative, Head of US Office for the Global Energy Assessment and Chair of the Global Climate Action Initiative established to assist international negotiators in the COP 15 and beyond processes.</p>
<p><b>JUDITH CURRY</b> Chair, School of Earth and Atmospheric Sciences, Georgia Institute of Technology. Very active on blog discussions concerning global warming over many years. Recently organized a special blog to facilitate such discussion. Henry G. Houghton Research Award from the AMS in 1992.</p>
<p><b>KERRY EMANUEL</b> Professor, Massachusetts Institute of Technology in Cambridge, MA. <u>Member of the National Academy of Sciences</u>. Named as one of <i>Time</i> Magazine's 100 Most Influential People (2006). AMS Rossby, Charney Awards, and many other awards and recognitions. Holder of the highest number of reference citations in the field of atmospheric science and tropical meteorology.</p>
<p><b>JAMES HANSEN</b> Head of the NASA Goddard Institute for Space Studies in New York City since 1981. Also adjunct professor of Earth and Environmental Sciences at Columbia University. Most famous of the global warming scientists – known throughout the world. Recipient of many awards for his outspoken warnings of the dangers to humankind of rising levels of CO<sub>2</sub>. Gave (now famous) US Senate testimony on the coming human-induced global warming in 1988. AMS Rossby Award.</p>
<p><b>ISAAC HELD</b> Head of the Weather and Atmospheric Dynamics Group at the Geophysical Fluid Dynamics Laboratory (GFDL). <u>Member of the National Academy of Sciences</u>, AMS Rossby Medal (highest award) and the AMS Meisinger Award. Fellow of the AMS, AGU.</p>
<p><b>GREG HOLLAND</b> Director, NCAR Earth System Laboratory. Former Director, Meso-scale and Micro-scale Meteorology Division, Earth and Sun Systems Laboratory, NCAR, Boulder, CO. Former Director of WMO Research Program on Tropical Meteorology. Long career in tropical meteorology. AMS Banner Miller and Max Eaton Awards.</p>

**PHIL JONES**

Director of Research, Professor in School of Environmental Sciences, University of East Anglia Climate Research Unit. Leading figure in IPCC reports and in the global warming field. Hans Oeschger Medal and other awards. One of the major targets of the Climategate e-mail revelation.

**MICHAEL MANN**

Professor of Atmospheric Science, Pennsylvania State University. Well known for research papers showing a large 20<sup>th</sup> century global warming with little or no Medieval Warming Period – the so called famous Hockey Stick (now discredited). Receiver of; Outstanding Scientific Paper award for 2002 by NOAA Office of Oceanic and Atmospheric Research. Named by *Scientific American* as one of 50 leading visionaries in science and technology (2002). Website “RealClimate.org” chosen as one of top 25 “Science and Technology” websites by *Scientific American*. Recently under investigation concerning his research activities at Penn. State University and the Univ. of VA related to the Climategate investigation.

**MICHAEL MACCRACKEN**

Chief Scientist for the Climate Change Programs at the Climate Institute in Washington DC. Very active in all aspects of AGW over the last two decades.

**CHRIS MOONEY**

Senior correspondent for *The American Prospect* magazine, author of 2 books, and co-author of a third book on climate. Visiting associate in the Center for Collaborative History at Princeton University. Author of NY Times best seller *The Republican War on Science* (2005), plus the books *Storm World* (2007) and coauthored *Unscientific American* (2009). Recently appointed to the board of the AGU. See section 7 titled Mooney’s Judgments for more information and discussion.

**BENJAMIN D. SANTER**

Lawrence Livermore National Laboratory climate researcher and former researcher at the University of East Anglia’s Climatic Research Unit. Member of the National Academy of Sciences. Very active in IPCC report activities. Strong proponent of human influence on global climate. MacArthur Foundation Genius grant recipient. Ernest Orlando Lawrence Award. Fellow of AGU.

**GAVIN SCHMIDT**

Climate modeler and climatologist at the NASA Goddard Institute for Space Studies. Organizer and supervisor of the influential Real Climate internet blog. Named one of *Scientific American’s* top 50 research leaders of the year.

**KEVIN TRENBERTH**

Head, NCAR Climate Analysis Section. AMS Charney Award, Fellow of AMS, AGU, AAAS. A strong and unbending advocate of human-induced global warming and especially increases in TC activity due to AGW. Principal player in all IPCC reports. Very **well-known** and influential in advocating CO<sub>2</sub>’s coming role in climate change.

**PETER WEBSTER**

Professor, School of Earth and Atmospheric Sciences, Georgia Institute of Technology. Former Chairman, University of Colorado, Atmospheric Science group. An Asian monsoon expert and **well-known** leader in the field of tropical meteorology. AMS Rossby and Charney Award recipient (and other awards), Fellow AMS, AGU and Royal Meteor. Soc.

**DISCUSSION.** It is surprising that such a group of prestigious scientists could all have been wrong in their assessment of the potential influence that CO<sub>2</sub> has on tropical cyclone activity? The overall influence of this prestigious group was a major problem for the media when faced with the need to write stories on the consensus view on the AGW-TC topic. The media would naturally be reluctant to go against such a prestigious group.

These senior scientists appeared to have simply pulled rank on the lower echelon and less prestigious scientists who were really more experienced and knowledgeable and tended to follow the data rather than a preconceived warming ideology. The media and the general public (not being informed enough to make scientific judgments) had to bend to the opinions of such a credentialed group. If such experienced and prestigious scientists can be wrong about a meaningful CO<sub>2</sub>-TC relationship, how right can we expect them to be on the question of CO<sub>2</sub> increase and global warming?

## PART II - SCIENTIFIC DISCUSSION

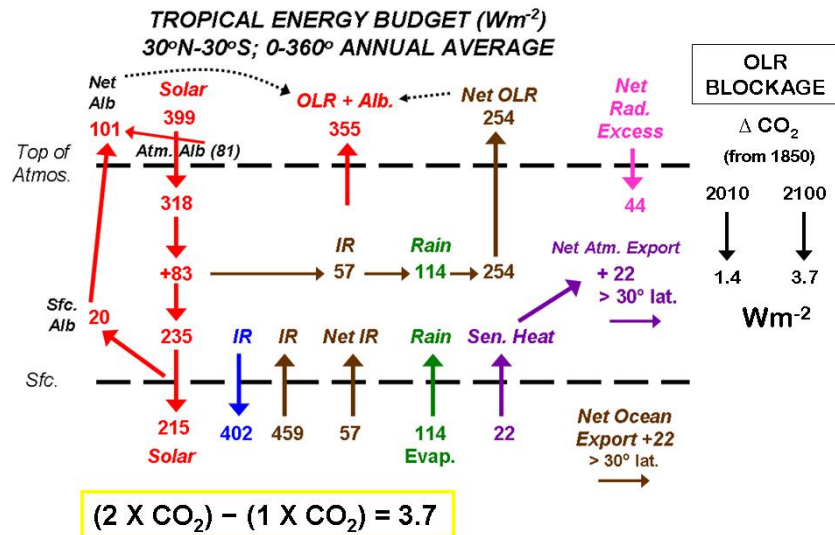
### 9. CO<sub>2</sub>'S MINISCULE ENERGY INFLUENCE ON TC ACTIVITY

My colleague, Barry Schwartz and I have been performing extensive data analysis with the International Satellite Cloud Climatology Project (ISCCP) and the National Center for Environmental Prediction (NCEP) Reanalysis data sets. We have used this data to make an annual average of the global tropical (30°N-30°S; 0-360°) energy budget (Figure 9.1) for the years from 1984-2004. Note that the various surface (459, 402, 215 Wm<sup>-2</sup>)<sup>2</sup> and top of the atmosphere energy fluxes (399, 355, 254 Wm<sup>-2</sup>) are very large. For the tropical surface, for instance, there are 637 Wm<sup>-2</sup> net units of downward incoming solar and infrared (IR) energy. This downward energy flux is largely balanced by an upward surface energy flux of 615 Wm<sup>-2</sup> which is due to upward energy transfer from IR, evaporated liquid water, and sensible heat.

It has been estimated that a doubling of CO<sub>2</sub> (from the pre-industrial period) without any feedback influences would result in a blockage of IR (or OLR) to space of about 3.7 Wm<sup>-2</sup>. The currently-measured value of CO<sub>2</sub> in the atmosphere is about 385 parts per million by volume (ppmv). If we take the background pre-industrial value of CO<sub>2</sub> to be 280 ppmv, then our globe should currently be emitting (from CO<sub>2</sub> increases alone up to now) about  $(105/280)*3.7 = 1.4$  Wm<sup>-2</sup> less IR (or Outgoing Longwave Radiation – OLR) energy flux to space than was occurring during the mid-19<sup>th</sup> century at the beginning of the industrial revolution.

---

<sup>2</sup> One Watt/m<sup>2</sup> equals one calorie/cm<sup>2</sup> per day.



**Figure 9.1** – Vertical cross-section of the annual tropical energy budget as determined from a combination of ISCCP and NCEP Reanalysis data over the period of 1984-2004. Abbreviations are IR for longwave infrared radiation, Alb for albedo and OLR for outgoing longwave radiation. The tropics receive an excess of about  $44 \text{ Wm}^{-2}$  radiation energy which is exported to latitudes poleward of  $30^{\circ}$ . Estimates are that about half ( $22 \text{ Wm}^{-2}$ ) of this export is transported by the atmosphere and the other half is transported by the oceans. Note, on the right, how small has been the OLR blockage that has occurred up to now due to  $\text{CO}_2$  increases ( $\sim 1.4 \text{ Wm}^{-2}$ ) and how generally small is the blockage of  $3.7 \text{ Wm}^{-2}$  that will occur from a doubling of  $\text{CO}_2$  by the end of this century.

This reduced IR energy flux of  $1.4 \text{ Wm}^{-2}$  is very small in comparison with most of the other tropical energy budget exchanges. Slight changes in any of these other larger tropical energy budget components could easily negate or reverse this small  $\text{CO}_2$ -induced OLR blockage up to now. For instance, an upper tropospheric warming by itself of about  $1^{\circ}\text{C}$  with no change in any other parameters would enhance IR (or OLR) energy loss ( $\sigma T^4$ ) to space sufficiently that it would balance the reduced IR warming influence from a doubling of  $\text{CO}_2$  ( $3.7 \text{ Wm}^{-2}$ ).

We anticipate that  $\text{CO}_2$  increases will bring about a negative water-vapor feedback influence (Gray and Schwartz, 2011) which will cause a  $3.7 \text{ Wm}^{-2}$  OLR blockage to space to be reduced by about two-thirds. Similarly, if there were only a slight reduction of upper tropospheric water vapor such that the long wave radiation emission level to space were lowered by about 10 mb ( $\sim 200 \text{ m}$ ), there would be an enhancement of OLR (with no change of temperature) sufficient to balance the suppression of OLR from a doubling of  $\text{CO}_2$ .

The  $1.4 \text{ Wm}^{-2}$  reduction in OLR we have experienced since the mid-19<sup>th</sup> century is very small in comparison with the overall  $399 \text{ Wm}^{-2}$  of solar energy impinging on the top of the tropical atmosphere or the mostly compensating  $356 \text{ Wm}^{-2}$  of OLR and albedo energy which the tropics radiates back to space. This  $1.4 \text{ Wm}^{-2}$  energy gain (0.39 of one percent of the net energy returning to space) is much too small to allow a determination of its possible influence on TC activity. Any such potential  $\text{CO}_2$  influence on TC activity would be deeply buried as turbulence within the tropical atmospheres many other larger energy components.

It is possible that future higher atmospheric CO<sub>2</sub> levels may cause a miniscule influence on global TC activity. But any such potential influence would likely be too small to ever be able to be reliably detected. And even if such a small influence were ever detected it would be swamped by the many other larger natural processes which are always at work to cause natural variations of TC activity. At the present time, we can only measure TC intensity to an accuracy of about 5 mph.

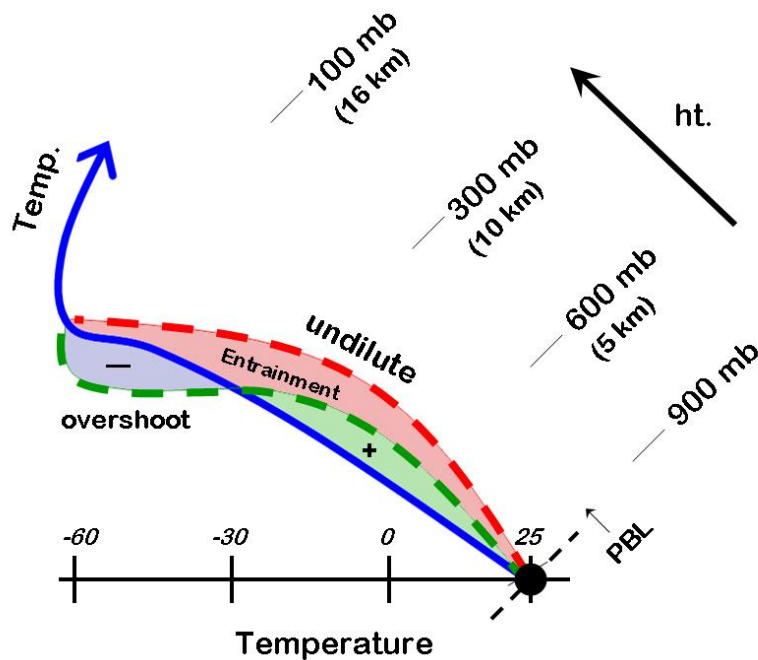
How can any sensible scientist (or meteorologist) ever anticipate that such a small influence from the extra blockage of IR to space of  $1.4 \text{ Wm}^{-2}$  would ever be able to bring about significant changes in TC activity as the many papers of Table 3.1 have implied or suggested are already taking place? The scenarios of these papers which discuss the importance of CO<sub>2</sub> increases on TC activity up to now are, from a relative energy magnitude point-of-view, ridiculous. It will be many decades before we will ever be able to detect a possible influence. Whenever any such changes may be able to be detected, they will undoubtedly be very small. At this stage, we cannot confidently determine if such small CO<sub>2</sub> influences might enhance or might reduce TC frequency or intensity.

**SUMMARY.** The authors of the many papers contained in Table 3.1 have greatly exaggerated the potential influence which rising levels of CO<sub>2</sub> can have on increasing SST and also on how rising levels of SST are able to have a significant influence on lapse-rate buoyancy.

## **10. WHY LONG-PERIOD CHANGES IN GLOBAL SST SHOULD HAVE LITTLE INFLUENCE ON LAPSE-RATE CONDITIONS OR TC ACTIVITY**

In a global world where there is climate warming or cooling, the atmosphere's upper air temperature and moisture conditions will warm or cool, moisten or dry in unison with surface temperature and moisture conditions. Positive lapse-rate buoyancy for deep cumulonimbus (Cb) convection, essential for the TC's existence, will not be significantly altered on the multi-decadal or multi-century time scales over which weak SST and moisture changes would occur in a slowly changing climate. Global energy budget considerations dictate that there can be only a small amount of global rainfall increase (2-3 percent) for a doubling of CO<sub>2</sub>. If rain changes are small, so also must be potential lapse-rate changes for Cb and towering cumulus convection which causes about two-thirds or more of global rainfall.

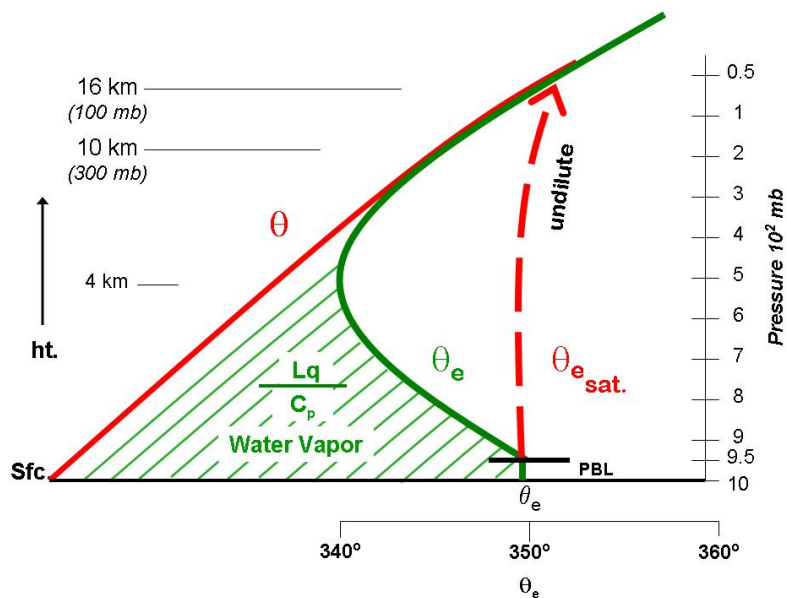
The typical lapse-rate buoyancy concept for Cb convection is shown in Figure 10.1. A parcel of air rising from cloud base (~960 mb or ~600m) in the tropics would follow the red dashed line if there was no inhibiting entrainment of dryer and cooler air into the rising parcel. But all deep upward accelerating air parcels entrain drier and cooler air to some degree. Most intense convective clouds tend to reach their maximum upward velocity and zero buoyancy level near 300 mb (~10 km).



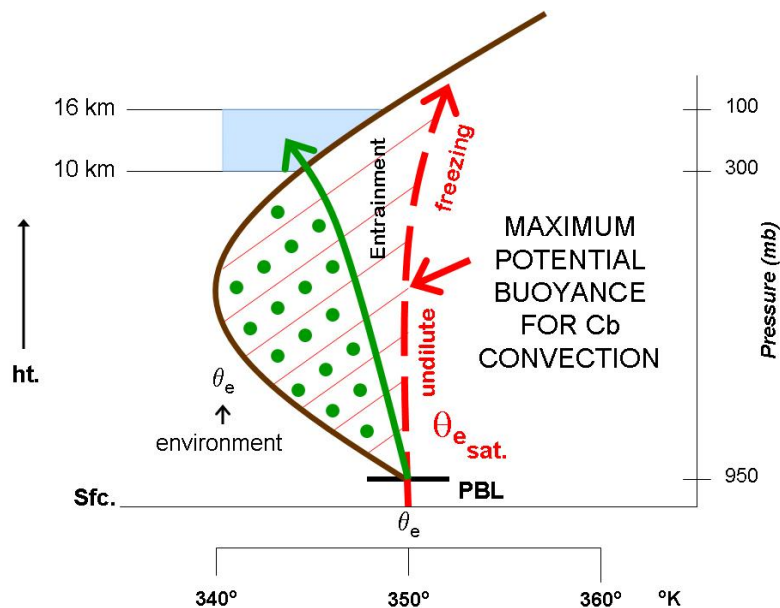
**Figure 10.1** – A tephigram thermodynamic diagram showing the typical tropical environmental lapse-rate temperature (blue) decrease with height and the expected temperature within a rising cumulonimbus (Cb) air parcel (in green). The green shaded area indicates the typical positive upward parcel buoyancy (or acceleration) and the blue area negative potential upward buoyancy and acceleration. The typical Cb air parcel reaches its maximum upward velocity near 300mb. It then overshoots into a layer of negative upward buoyancy (blue) which slows the parcel's vertical velocity to zero below the tropopause (~13-16 km). The red curve shows the very large upward buoyancy that a rising upward air parcel would have if it experienced no entrainment of sub-saturated and cooler air to weaken it. This is rarely observed. Almost all Cb updrafts experience some degree of entrainment.

In addition to Figure 10.1, the concept of the potential and actual buoyancy of deep Cb convection can also be thought of from the point-of-view of the vertical gradient of equivalent potential temperature<sup>3</sup> ( $\theta_e$ ) or moist static energy ( $h$ ). The vertical variation of environmental  $\theta_e$  is composed of the vertical increase of potential temperature ( $\theta$ ) – in combination with the vertical variation of moisture content of the air converted to temperature ( $^{\circ}\text{K}$ ) or  $Lq/C_p$  (Figure 10.2), where  $q$  is the air's specific humidity or moisture content in units of grams of water vapor per kilogram of dry air. Figure 10.3 is similar to Figure 10.1 and shows how a typical Cb updraft  $\theta_e$  (in green) is decreased due to entrainment. Like the tephigram portrayed in Fig. 10.1, the typical parcel runs out of positive upward acceleration (or buoyancy) near 300 mb (10 km).

<sup>3</sup> Typical vertical variation of equivalent potential temperature  $\theta_e$  or  $1/C_p [(T + gZ + Lq)]$  expressed in  $^{\circ}\text{K}$  where  $C_p$  is specific heat at constant pressure,  $g$  is gravity,  $z$  is height,  $L$  is latent heat of condensation and  $q$  is specific humidity in grams of water vapor per  $10^3$  grams of air. The similar expression of  $C_p T + gZ + Lq$  is also known as moist static energy (or  $h$ ).



**Figure 10.2** – Illustration of how the typical tropical vertical variation of equivalent potential temperature  $\theta_e$  (green) changes with height and is composed of the typical vertical change of potential temperature ( $\theta$ ) and the typical vertical change of the energy equivalent of water vapor ( $Lq/C_p$ ) expressed in units of  $^{\circ}\text{K}$ . The vertical increase of  $\theta$  is very close to being linear with pressure decrease. The red dashed line denotes the conservation of saturated equivalent potential temperature ( $\theta_{es}$ ) upward from the top of the PBL with assumed cloud drop particle freezing at temperatures of 10-30 $^{\circ}\text{K}$  below freezing.



**Figure 10.3** – Cumulonimbus (Cb) parcel buoyancy from the perspective of the vertical variation of  $\theta_e$ . Cb parcel's maximum potential updraft buoyancy will occur if it rises from the top of the PBL without any entrainment of environmental air into the parcel (undiluted ascent – red dashed line). Entrainment however, will cause the typical parcel to follow the green curve to the left. The hatched area to the left of the green line is a measure of the potential updraft buoyancy of the typical Cb updraft parcel undergoing entrainment. The parcel loses its positive buoyancy near 10 km and then encounters the negative buoyancy of the blue area which weakens its upward velocity to zero.

**MAINTENANCE OF DEEP CUMULUS CONVECTION.** In the tropical areas where TCs form in the late summer-early fall, it is well known that conditionally unstable lapse-rate conditions are always present and typically do not vary much in magnitude during the TC season. The main variable is middle-level moisture content. Low-level cumulus convection can always develop with any significant degree of low-level upward mechanical forcing. Special environmental conditions are required for the maintenance of large numbers of deep Cb clouds that extend through the greater part of the troposphere, however. The development and maintenance of tropical cloud clusters containing many oceanic Cb convection elements requires:

1. Synoptic scale frictionally forced mass convergence which produces concentrated meso-scale areas of convergence over a typical area of about 200-300 km on a side. This concentrated meso-scale convergence will act to initiate isolated local areas of deep cumulus convection. But this horizontally forced meso-scale area of low-level convergence is never strong enough to be able to maintain 20-30 or more simultaneous deep convective Cb elements on a continuing basis. For the maintenance of such large numbers of convective Cb elements (which are required for cloud cluster formation and TC formation), it is necessary that the clusters of Cb clouds in the meso-cluster system exist in relatively close proximity to one another. This is needed so that the raining downdrafts of the convective Cb elements are able through cloud drop evaporation cooling and raindrop loading to develop strong downdraft cells which are able to bring down enough mass into the tropical planetary boundary layer (PBL) to be able to form new convective units. This is necessary so as to cause local areas of very high mechanically forced mass convergence in the PBL. Individual Cb elements typically only exist for an hour or less. A continuous supply of downdraft mass flux into the PBL is necessary to maintain the needed mechanically forcing of new cumulus updraft parcels. These cumulus updraft parcels must have enough mass that they are both strong enough and wide enough to be able to withstand the inhibiting effects of entrainment as they vertically extend into the upper troposphere. This is the only way meso-scale areas can be continuously maintained as tropical disturbances and depressions for 2-4 days before other changes are able to take place to allow TC initialization and intensification to proceed. And the hurricane maintains even stronger downdraft conditions within its inner cloud area.

It is important to realize that the mean synoptic and meso-scale mass convergence into the tropical cloud cluster is not sufficient for the maintenance of a disturbance's many Cb convective elements. By a ratio of 5-10 to one, the mass convergence into the PBL necessary for the development of new Cb convective elements must be produced by the downdrafts from earlier deep cumulus cloud elements (see Lopez, 1973a, 1973b and Gray, 1973).

2. An environment of relatively high middle-level cloud cluster relative humidity (RH) is needed to allow convective air parcels (that will become deep Cb cloud towers) to be able to withstand the entrainment of sub-saturated air into them. Cumulus updrafts cannot maintain their buoyancy if large amounts of sub-saturated air are entrained into them. It is well known that tropical depressions and hurricanes weaken if they advect middle-level dry air into or through their circulation. To maintain saturation within

updraft cumulus parcel that is entraining sub-saturated air, it is necessary that some of the updraft cloud particles be evaporated. For every required gm of cloud drop water that is evaporated per kg of air within the updraft (to maintain parcel saturation), there is a cooling of 2.4°C within this kg of air. Such evaporative cooling due to entrainment cooling can exert a strong inhibiting influence on an updraft's buoyancy. This is another reason why meso-scale tropical cloud clusters must exist in groups where middle-level relative humidity (RH) between convective cloud elements remains near 50 percent rather than the usual RH which exists in typical tropical middle and upper tropospheric clear or scattered cloud areas of 25-40 percent.

**ENTRAINMENT PHYSICS.** All forming cumulus clouds start out as accelerating updraft air parcels from the PBL. This causes a slight rising of the pressure within the upward forward edge of the updraft parcel as it pushes away the new air with which it comes into contact. The opposite occurs on the lower or back part of the updraft. This reduced pressure within the lower part of the updraft causes surrounding air to converge into it. This slight weakening of the vertical pressure gradient also acts to reduce the parcel's upward acceleration to a small degree. Vertical and horizontal wind shears around the growing updraft parcel can also cause a degree of mechanical mixing into the updraft parcel. The sum of these processes is called entrainment.

All accelerating updraft parcels have varying amounts of entrainment which act to reduce their upward vertical acceleration from undiluted ascent. Entrainment restrictions on parcel buoyancy occur by three processes:

1. Convergence of sub-saturated air parcels into the saturated updraft. This requires that some of the cloud drop particles within the saturated updraft must be evaporated in order that the parcel maintains saturation. This acts to inhibit the rate at which condensation warming occurs.
2. Convergence into the updraft of surrounding air which is slightly cooler than the updraft air. This also acts to reduce the parcel's upward buoyancy but is, typically less important than 1.
3. Development of a slightly reduced upward vertical pressure gradient from precise hydrostatic balance as a result of the higher pressure to the parcel's forward side to a slightly reduced pressure on its lower side. This also acts to slightly weaken the parcel's updraft velocity.

These three processes acting together cause a reduction in all updraft parcel's buoyancy and vertical motion.

Updraft modeling and empirical studies have demonstrated (Lopez, 1973a and 1973b) that the amount of an updraft parcel's entrainment or the amount of updraft weakening from entrainment is:

1. Inversely proportional to the area of the updraft. Wide updrafts have smaller amounts of relative entrainment than do narrow parcels if all other factors are the same.

2. Inversely proportioned to the strength of the parcel's mechanical updraft velocity at cloud base. Stronger initiated updraft cumulus cloud parcels have lesser relative rates of entrainment than do weaker ones if all other factors are the same.

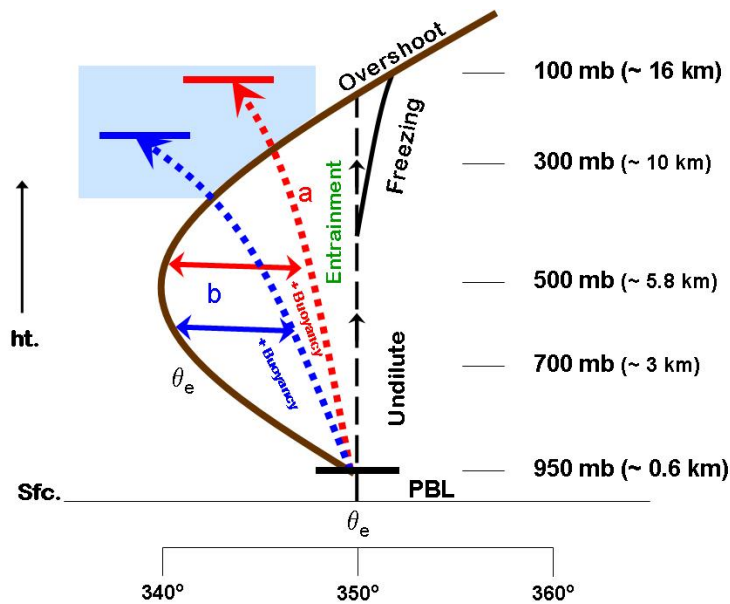
Net entrainment into an updraft parcel is thus an inverse function of the product of the area of the updraft parcel ( $A_p$ ) and the parcel mean updraft velocity at cloud base ( $\omega_p$ ) or  $\frac{1}{(A_p)(\omega_p)}$ .

Thus, the wider (or greater area) of the initiated updraft parcel at cloud base, the lesser is the relative inhibiting influence of entrainment. The stronger is the initiating mechanically forced updraft parcel velocity at cloud base, the lesser is the parcel's rate of relative entrainment. Figure 10.4 shows how two updraft parcels which start out at the same cloud base level reach different heights due to the varying amounts of entrainment they encounter even though their lapse-rates are the same. Differences lie in the strength and frequency of the downdraft forcing. The initiating size and intensity of the updraft forcing largely determines the relative amount of entrainment each parcel will encounter.

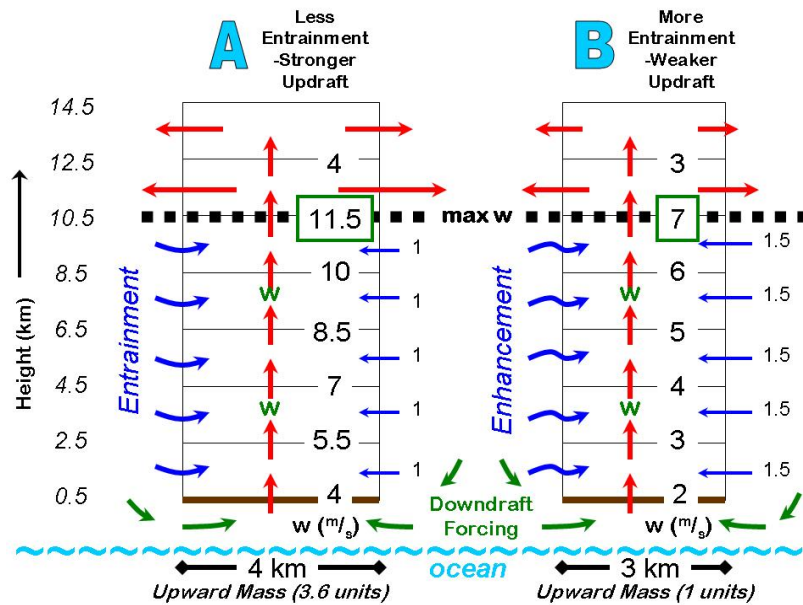
Figure 10.5 shows the case where an idealized updraft of 4 km width and 4 m/s maximum forcing at cloud base (sinusoidal curve with maximum updraft at 90° or 2 km from the edge – mean .67 of maximum). This is assumed to produce a maximum updraft at 10.5 km altitude which is 11.5 m/s. This is compared to a 3 km wide updraft with a maximum mechanical forced updraft at cloud base of 2 m/s (1.33 mean) which produces an estimated maximum updraft velocity at 10.5 km of 7 m/s. The stronger updraft Cb brings about 3.6 times more mass to the upper troposphere even though the lapse-rates in both cases were similar. The character of the tropical disturbance's net up-and-downdraft convective patterns plays as important and at times a more dominant role in the amount and intensity of deep cumulus as do SST and lapse-rate buoyancy variations.

Figure 10.6 and 10.7 give idealized views of how long period climate changes in global tropical SSTs should be expected to bring about little change in the vertical stability from both the equivalent potential temperature ( $\theta_e$ ) or from the tephigram lapse-rate diagram perspective.

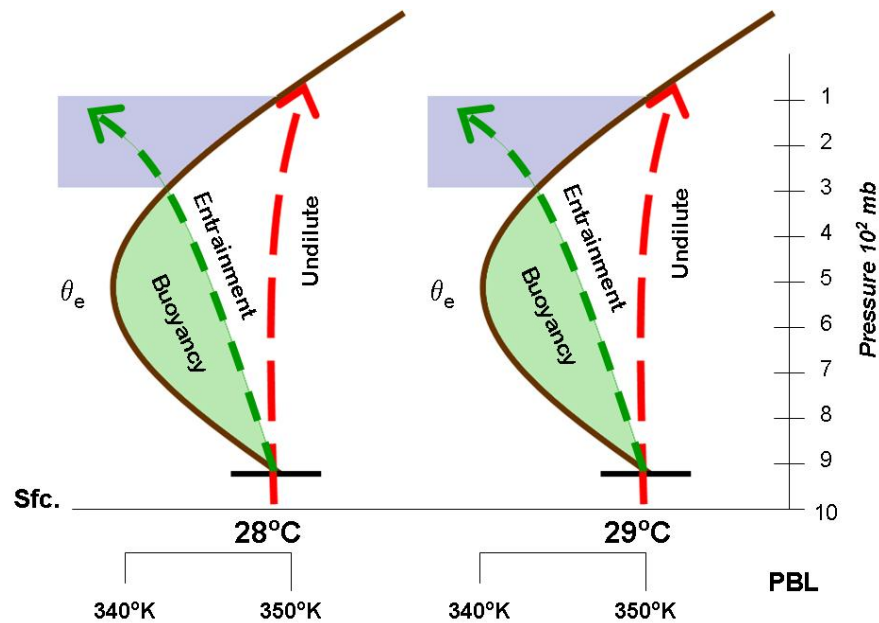
These figures demonstrate that it is possible to have similar vertical lapse-rate buoyancy where tropical SSTs are 1°C different from one another. The updraft parcel buoyancy is given by the area to the right of the  $\theta_e$  curve. By considering the extra heat of fusion (80 cal/gm) when liquid water is changed to ice between -10 to -30°C, the undiluted and freezing air parcel could even go higher. If global rainfall is not to be changed more than 2-3 percent for a doubling of CO<sub>2</sub> or for small global temperature changes of a half to 1°C, then one should not expect significant change in lapse-rate conditions or in TC activity.



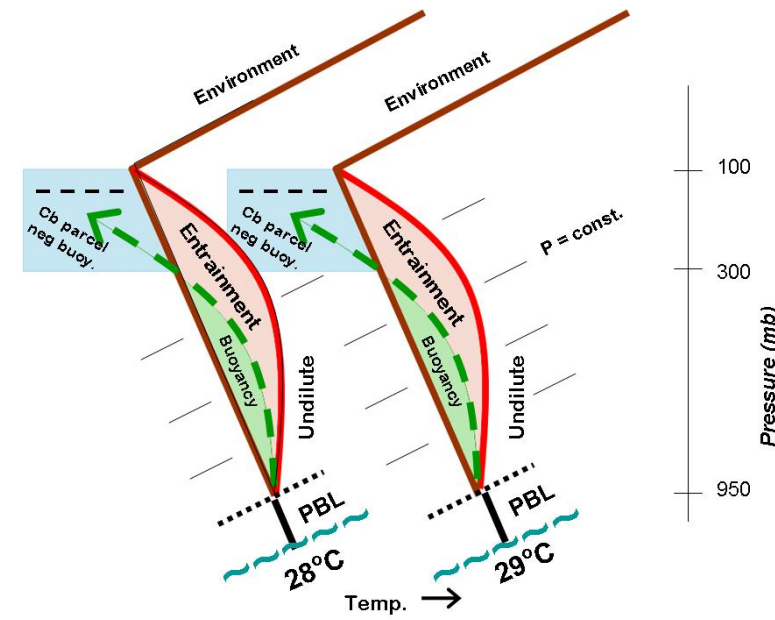
**Figure 10.4** – Illustration of how variations in updraft parcel buoyancy can occur in an identical lapse-rate environment due to variations in updraft entrainment resulting from the initial width of the updraft at cloud base and the initial strength of the cloud-base updraft forced vertical motion. Cb updraft parcels have less updraft-inhibiting side entrainment if they start out at cloud base being wider and if they have more initial cloud-base upward mechanical forcing from surrounding downdraft mass convergence into the PBL. Parcel a's updraft buoyancy strength and level of crossover to negative buoyancy is at a higher level and is stronger than parcel b's reduced buoyancy and reduced level to crossover to negative buoyancy. Updraft a is a Cb while updraft b is a towering cumulus.



**Figure 10.5** – Idealized portrayal of parcel updraft velocity (in m/s) as a function of the updraft width (4 vs. 3 km) and mechanically forced maximum updraft velocity (4 vs. 2 m/s). Lapse-rates are identical. Updraft parcel A is assumed to have a relative effective entrainment rate of 1 while parcel B has a relative effective entrainment rate of 1.5. Parcel A has a maximum velocity at 10.5 km altitude of 11.5 vs. 7 m/s of parcel B. Parcel A transports 3.6 times more mass above 10.5 km as does parcel B.



**Figure 10.6** – Portrayal of how increasing SST from 28°C to 29°C over a long adjustment time period would not appreciably change the positive area of Cb potential buoyancy. Although the  $\theta_e$  of the PBL would rise in the 29° SST parcel, so too would the  $\theta_e$  of the upper troposphere. Although this rise in upper level  $\theta_e$  would be smaller, it would occur through a deeper layer and be sufficient such that the net potential Cb buoyancy up to 300 mb would not appreciably change. A global climate specifying that late summer SSTs in the TC genesis areas are 29°C should not be expected to necessarily have more intense Cb convection than in a cooler net global climate environment where late summer SSTs in the TC areas were specified to be 28°C.



**Figure 10.7** – As in Figure 10.6 but where buoyancy is expressed in Tephigram form with Cb buoyancy expressed as the temperature of the updraft parcel minus the temperature of the updraft's surrounding environment.

**CLIMATOLOGICAL CONSIDERATIONS.** I have previously shown that the climatological aspects of the seasonal frequency of tropical cyclone formation at any global location are closely related to the product of six seasonally averaged parameters (Gray 1975, 1979). They are:

1. The Coriolis parameter ( $f$ )
2. Low-level relative vorticity ( $\zeta_r$ )
3. Inverse of the tropospheric vertical wind shear ( $1/S_z$ )
4. Ocean thermal energy, manifested as ocean temperatures greater than  $26^\circ\text{C}$  to a depth of 60 meters [ $E$ ]
5. The difference in equivalent potential temperature between the surface and 500 mb ( $\Delta\theta_e$ ).
6. Relative humidity in the mid-troposphere (RH) – 700 mb and 500 mb.

The product of parameters 1, 2, and 3 specifies a dynamic potential ( $f \zeta_r / S_z$ ), while the product of parameters 4, 5 and 6 yields a thermal potential ( $E \Delta\theta_e \text{ RH}$ ). Multiplying both dynamic and thermal potentials together specifies a “seasonal genesis parameter” which provides a very good estimate of the long-term frequency of occurrence of tropical cyclones at all global locations for each season of the year.

The seasonal genesis parameter may also be thought of in the form of:

$$\text{Seasonal Genesis Parameter} = (\text{Dynamic Potential}) \times (\text{Thermal Potential})$$

where

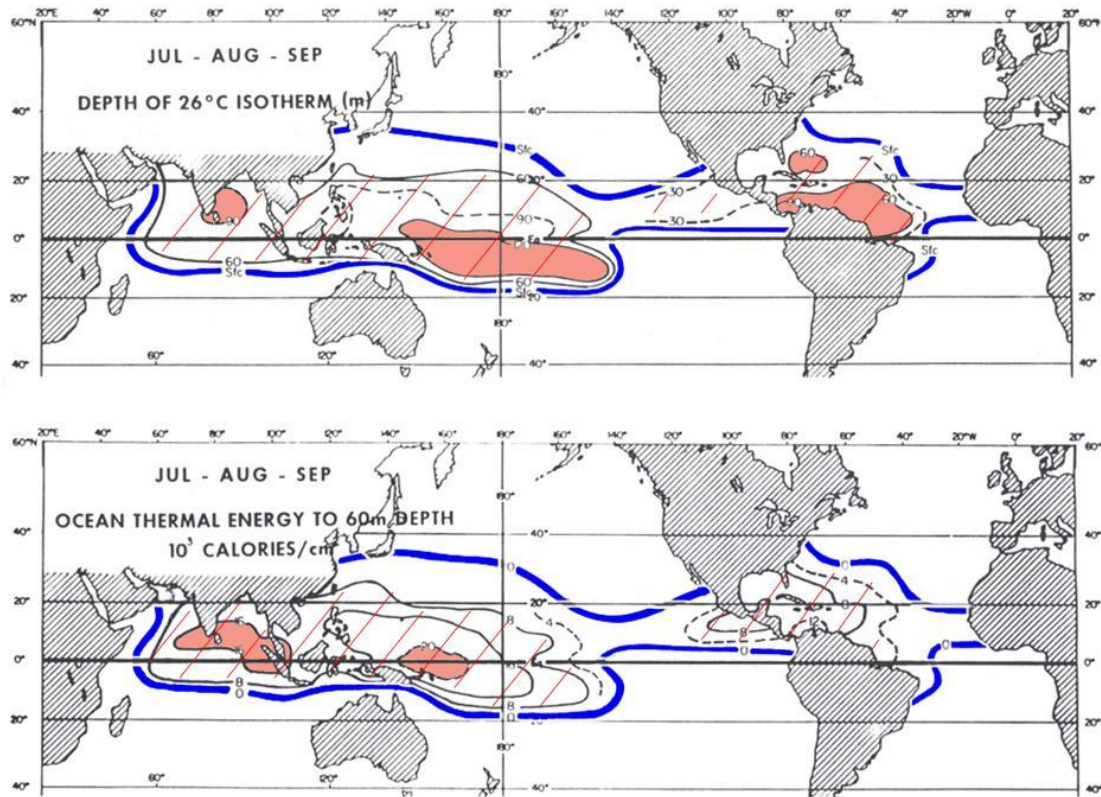
$$\text{Dynamic Potential} = (f) (\zeta_r + 5) [1 / (S_z + 3)]$$

$$\text{Thermal Potential} = (E) (\delta \theta_e / \delta p + 5) (\text{RH Parameter})$$

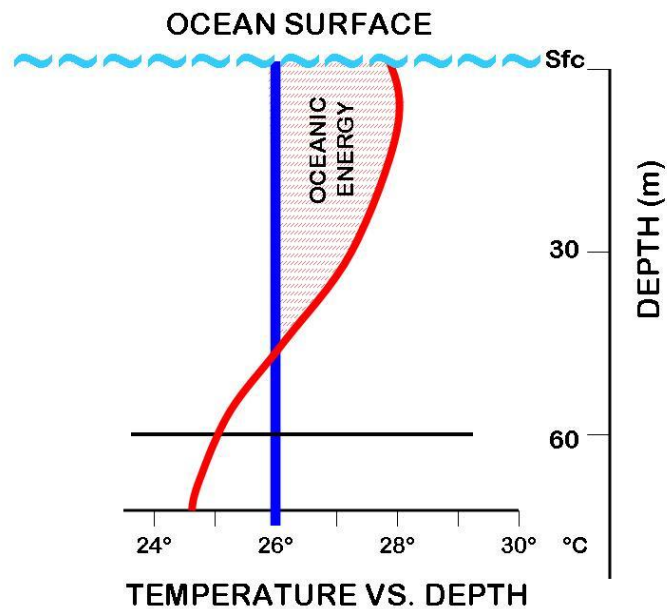
where the values 5 and 3 are empirical scaling factors.

It is remarkable that the frequency of a phenomenon as variable as tropical cyclones should have such a close association with the long-term climatology of seasonally averaged parameters. This association is an indication of how tropical cyclones are, to a high degree, a consequence of the large-scale climatological conditions existing in each formation region.

Note that this genesis parameter has no explicit reference to SST. This implies that SST, by itself, is not a primary determiner of TC frequency. It is much more important that deep warm ocean water greater than  $26^\circ\text{C}$  extends downward to 50-100 m depth, so that cool-dry downdrafts into the PBL can be more readily ‘recharged’ to warmer and moister air. See Figures 10.8 and 10.9 for illustrations of how deep warm water can extend in various tropical regions.



**Figure 10.8** – July through September climatology of the depth of 26°C water in meters (top) and the net ocean thermal energy above 60 m depth in units of 1000 cal/cm<sup>2</sup> (bottom) – Gray (1979).

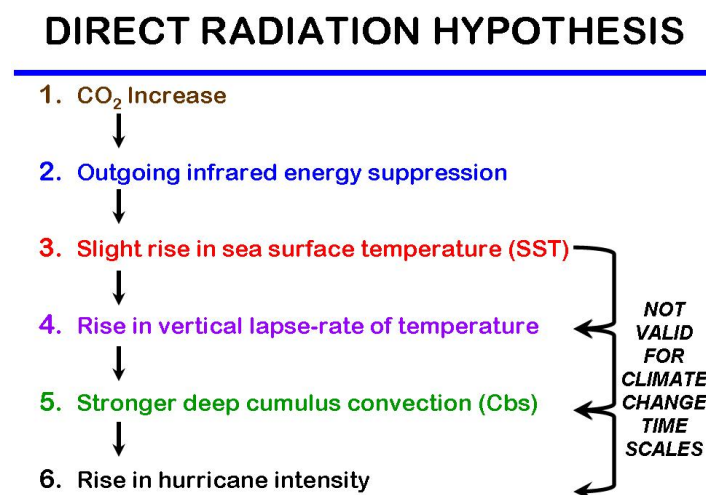


**Figure 10.9** – Cross section view of the typical ocean temperature decrease with depth and how the ocean thermal energy is defined (the area to the right of the 26°C isotherm to a depth of 60 m) – (Gray 1979).

**CONFUSING LOCAL AND CLIMATE TIME SCALES.** A hurricane passing over a warmer body of water, such as the Gulf Stream, will often undergo a degree of intensification. This is due to the sudden lapse rate increase which the hurricane's inner core experiences when it passes over warmer water. The warmer SST causes the hurricane's inner-core PBL temperature and moisture content to rise. While these low-level changes are occurring, upper tropospheric conditions are typically not being altered. These rapidly occurring lower- to upper-level potential buoyancy increases can cause the inner-core hurricane lapse-rates to increase and likely produce more inner-core deep Cb convection. This can cause an increase in the hurricane's intensity. Such observations and the clear association of the most intense individual typhoons and hurricanes with the highest SSTs has led many observers to directly correlate SST with hurricane intensity on longer-period climate scales. This is valid reasoning for local and day-to-day hurricane intensity changes that are associated with hurricanes moving over warmer or colder patches of SST. But such direct reasoning does not hold for conditions occurring in a climatologically altered tropical ocean environment where upper tropospheric temperature and moisture conditions have had time to become adjusted to a warmer or cooler and moister or dryer PBL. Such balancing upper and lower tropospheric mutual adjustments inhibit lapse-rate alteration. We should not expect that the frequency and/or intensity of Cat. 4-5 hurricanes will necessarily change if the globe should become somewhat warmer or somewhat cooler.

This analysis is contrary to the general physical reasoning of the many papers listed in Table 3.1. Most of these papers hypothesize a climatologically direct linkage between rising SST values and rising levels of TC activity. This is not a valid assumption on a climate change time scale.

**EVIDENCE OF LITTLE SST-TC ASSOCIATION ON SEASONAL TIME SCALES.** The physics of those proposing a direct physical link between rising levels of CO<sub>2</sub> and TC activity is given in Figure 10.10. This is a plausible physical argument over a short period. But on the climate time-scale the assumed linkage between steps 3 to 6 is not valid.

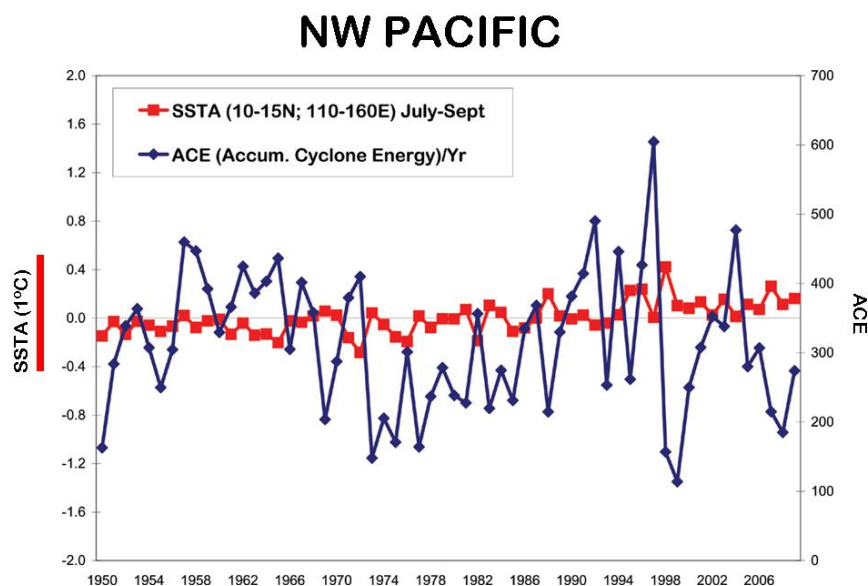


**Figure 10.10** – Physical reasoning of those who believe that increases in CO<sub>2</sub> should make hurricanes more intense and more frequent (left arrows). The problem is the assumed direct linkage between steps 3 to 6, which are not valid and climate scale time changes.

Figure 10.11 shows the year-by-year variation of late summer SSTs in the primary TC formation area in the NW Pacific with yearly variations of Accumulated Cyclone Energy (ACE). Note the lack of a clear association. Similar figures have been constructed for the other global storm basins. Table 10.1 shows the correlation of seasonal ACE with late summer-early fall SSTs in the Northeast Pacific, the Northwest Pacific, and the Southern Hemisphere. Note the low (or even negative) correlations between ACE and SST in each of these TC basins. It is obvious that other physical processes besides SST changes are responsible for differences in net seasonal TC activity. There is an association of warmer SSTs in the Atlantic Ocean. More intense TCs form in the main development area ( $10^{\circ}\text{N}$ - $20^{\circ}\text{N}$ ;  $60^{\circ}\text{W}$ - $20^{\circ}\text{W}$ ) when SSTs are higher. But this (as is discussed in section 13) is due primarily to changes in other large-scale factors (vertical shear, trade-wind strength, moisture) which themselves and the SSTs are driven by fluctuations in the strength of the THC.

**TC ASSOCIATIONS WITH DISTANT SST PATTERNS.** There are SST patterns removed from the various TC basins which, nevertheless, are known to be associated with alterations in TC activity at distant locations. For instance, Atlantic seasonal TC activity is typically enhanced or typically reduced when positive or negative SST anomalies are present in the far North Atlantic ( $50$ - $65^{\circ}\text{N}$ ;  $10$ - $50^{\circ}\text{W}$ ). These Atlantic SST patterns are associated with the changing strength of the Atlantic Thermohaline Circulation (THC) or the Atlantic Multi-decadal Oscillation (AMO).

Northwest Pacific typhoons are known to typically form further eastward and have longer tracks during El Nino years. It is well known that tropical Atlantic basin hurricane activity is strongly suppressed in El Nino years when eastern equatorial Pacific SSTs become abnormally warm.



**Figure 10.11** – Late summer SST (red) in the primary NW Pacific TC formation vs. NW Pacific seasonal Accumulated Cyclone Energy (ACE) – in blue. Note the lack of an association. ACE data from R. Maue.

**Table 10.1** – Correlation of yearly ACE with late summer-early fall SST in three non-Atlantic TC basins over the last 30 years. ACE is the sum of the squares of each named TC’s maximum wind ( $V_{max}$ ) at each 6-hour period for an entire season. ACE data from R. Maue.

	Yearly Mean ACE	ACE vs. SST Correlation
Northeast Pacific SST (10-15°N)	134	0.01
Northwest Pacific SST (10-15°N)	310	-0.30
S. Hemisphere SST (10-15°S; 50°E-135°W)	205	0.23
Globe SST (20°N-20°S)	769	-0.08

These differing regional SST patterns are at locations which are removed from where the individual cyclones form. Their influence on hurricane enhancement or suppression is usually not related to changing lapse-rate buoyancy or SSTs at the locations of the TCs. Rather, these distant SST patterns are more associated with changes of other known and required features for TC formation and intensity change – such favorable features as reduced tropospheric vertical wind shear, stronger positive low level vorticity, more rainfall, lower surface pressure, higher middle-level moisture, etc. This has also been discussed by Vecchi and Soden (2007).

**DISCUSSION.** Observations show that upper tropospheric horizontal gradients of  $\theta_e$  over the TC basins show substantially less variability than do horizontal  $\theta_e$  gradients within the PBL. Pockets of higher or lower PBL temperature and moisture lead to local areas of higher or lower lapse-rate buoyancy and thus varying degrees of potential Cb convection strength.

We usually observe higher intensity hurricanes in oceanic areas of higher SST. These observations should not be used to exaggerate the importance of SST as a primary distinguisher for TC frequency and intensity for long-period climatologically altered environments where upper and lower temperature conditions have had time for adjustment. Also, when higher SSTs are present during active TC periods, other required TC formation and intensity parameter conditions are typically also present (vertical shear, low-level vorticity, middle-level moisture, etc.) and play as large or larger role than the differing SST values.

**SUMMARY.** This discussion goes opposite to what so many scientists currently assume to be a direct association between SST increases, cumulus potential lapse-rate buoyancy, and hurricane activity. Their thinking is valid in individual cyclone cases but not valid on the longer period climate time scales where the entire global system has had time to become in balance to a new circulation state. The change of tropical SSTs over the entire tropics and globe during long time periods of decades to a century should not be assumed to automatically bring about any systematic increases or decreases in TC intensity or frequency.

## 11. FUNDAMENTAL IMPORTANCE OF CONVECTIVE DOWNDRAFTS AND MASS RECYCLING WITHIN ORGANIZED TROPICAL SYSTEMS

Most meteorologists think of the organized tropical cloud cluster and typhoon-hurricane weather system as having a strong transverse (or 'in-up-and-out') circulation of low-level frictionally driven inflow, upward vertical motion in cloud areas, and outflow at upper tropospheric levels. Tropical weather systems also have another fundamentally important circulation within them which is an additional 'down-and-up' (or downdraft-and-updraft) circulation associated with evaporating downdraft motion and mass compensating condensation upward motion. This additional 'down-and-up' circulation has yet to be fully recognized and fully appreciated.

This section emphasizes the fundamental role of this additional 'down-and-up' circulation which must be added to the accepted 'in-up-and-out' basis transverse circulation to obtain a full understanding of the tropical weather system's complete vertical circulation structure. Only by adding this additional extra 'down-and-up' is it possible to make simultaneous mass, energy, and moisture budgets for this class of weather system. This additional 'down-and-up' (or downdraft-and-updraft) circulation is indispensable in allowing tropical systems to extract large amounts of required surface energy from the oceans.

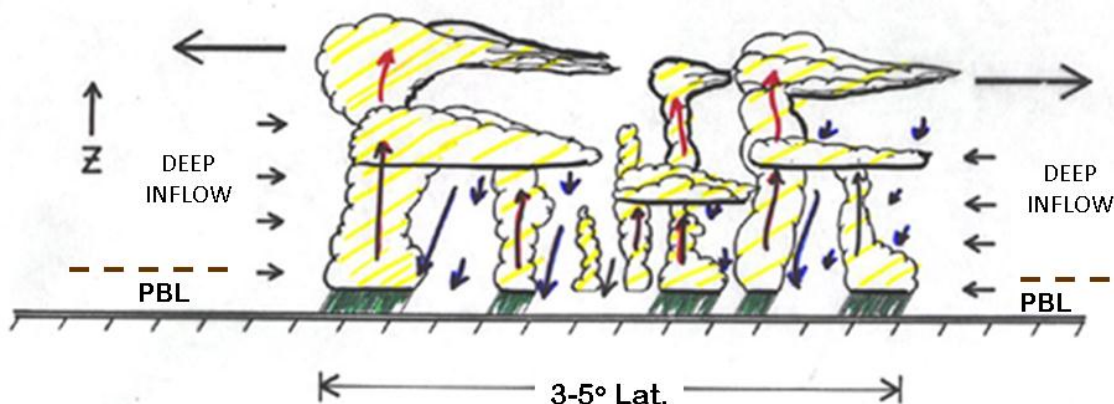
In and around the meso-scale upward vertical motion rain areas within tropical cloud clusters there is also a great deal of additional mass compensating downdraft-and-updraft vertical motion in the lower two-thirds of the troposphere. This is superimposed on the mean upward vertical motion within the cluster system (Figures 11.1-11.6). This extra mass balancing downdraft-and-updraft motion (or 'down-and-up') is associated with large amounts of negatively buoyant rain-induced downdraft motion. This results from the evaporation cooling of raindrops and the heavy rain water loading within the convective areas. This downdraft motion plays a fundamental role in mechanically forcing new convective updraft elements within the Planetary Boundary Layer (PBL). The lifetime of individual convective elements is short and new convective elements must continually be generated to balance the mass coming into the PBL from the downdraft elements and from the frictional- and meso-scale-driven horizontal convergence.

As with the previous Figures 10.1 through 10.7 discussion on upward convective cloud parcels, there is also the opposite convective rain-cloud regions of enhanced air density and negative buoyancy. These downdrafts experience large amounts of evaporation cooling in order to sink. Their air comes down cool and saturated or near-saturated. They descend into the PBL carrying their cooler-drier air and higher horizontal wind speeds with them.

Downdrafts usually act to accelerate the cloud cluster's low-level winds. They also often act as a meso-scale change mechanism for the cloud cluster to transform itself from a cold-core system (highest winds near middle-levels) to a warm-core system with maximum tangential wind speeds being altered from the middle to low tropospheric levels. Such a transformation tends to occur where the clouds tend to form bands and align themselves crudely parallel to the pre-TC's troposphere vertical wind shear vector. Figure 11.3 is an example of the

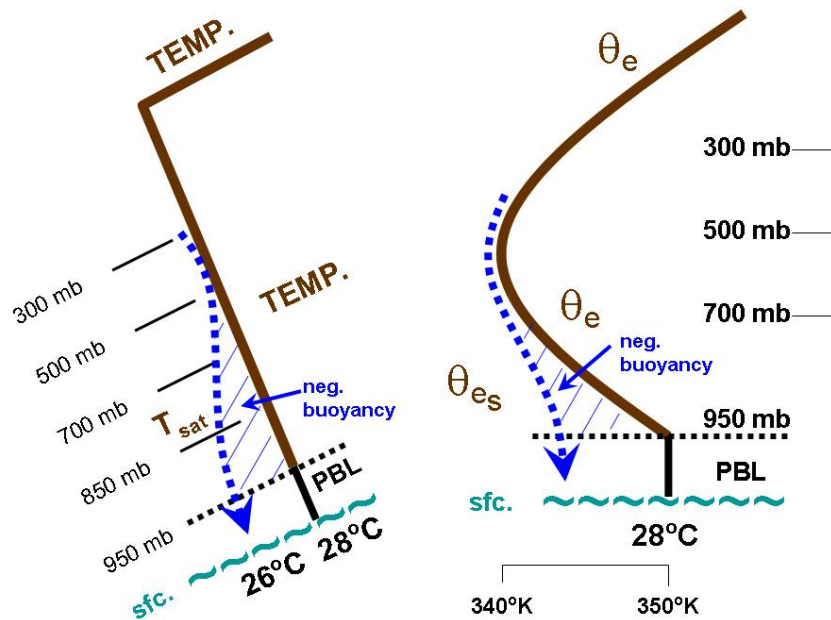
arrangements of radar (C-band) observed rain areas of the early stage development of pre-hurricane Carla (1961) on 6 September. Note the early beginning alignment of the cloud lines (I was on this flight and made this radar composite).

New Cb cloud generation is facilitated by having the heavy rain clouds lining up into bands. This enhances downdraft winds and the mechanical forcing of new convection elements. Line or banded Cb convection also carries tangential momentum into the upper troposphere and allow storm outflow to extend to larger radius (Lee, 1984).

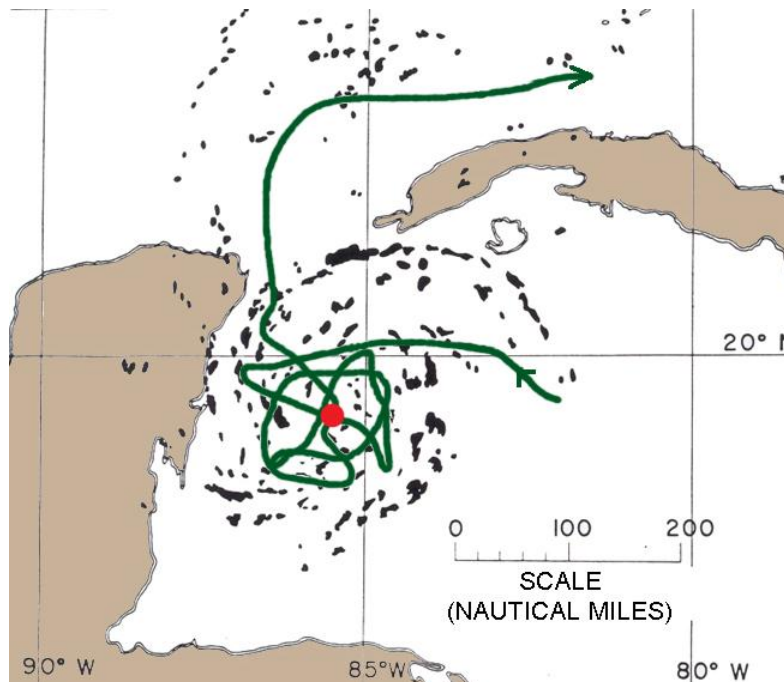


**Figure 11.1** – Section of a typical pre-TC cloud cluster showing the deep tropospheric inflow layer of which only a small fraction of this air is entrained directly into the cumulus updraft convection to exit in the outflow layer. The majority of this upper inflow mass goes into downdrafts which sink into the PBL and drive new convective elements.

Years of rawinsonde composite analysis on the author's research project has verified that the typical well-developed meso-scale tropical cloud cluster has a very deep inflow layer up to 400-300 mb (9-10 km) and a concentrated outflow centered between 200 and 150 mb. The left diagram of Figure 11.4 shows this typical deep inflow and upper tropospheric outflow pattern of a variety of different types of cloud clusters and a cloud-clear region for comparison. The right diagram shows the resulting mass conserving mean 0-4° radius vertical motion pattern with the steady increase of vertical motion to 400-300 mb. This steady upward vertical motion profile implies that all the inflowing air below 300-400 mb rises to the outflow level and exits the system. This is not possible because most of the inflowing sub-saturated air converging into the cluster system above 900 mb does not possess upward potential buoyancy after it has been raised to its level of saturation. Some of it (likely 15-20% or so) is entrained into the deep Cb updraft elements whose extra-strong upward buoyancy is able to overcome this smaller amount of entrained negatively buoyant air. The rest of the middle-level inflowing must sink in downdraft motion.



**Figure 11.2** – Illustration of negative buoyancy from both the tephigram (left) and vertical  $\theta_e$  profile points-of-view (right). Downdrafts (in blue) result from evaporation cooling with sinking warming vapor advection increase which maintains downdraft parcels near saturation.

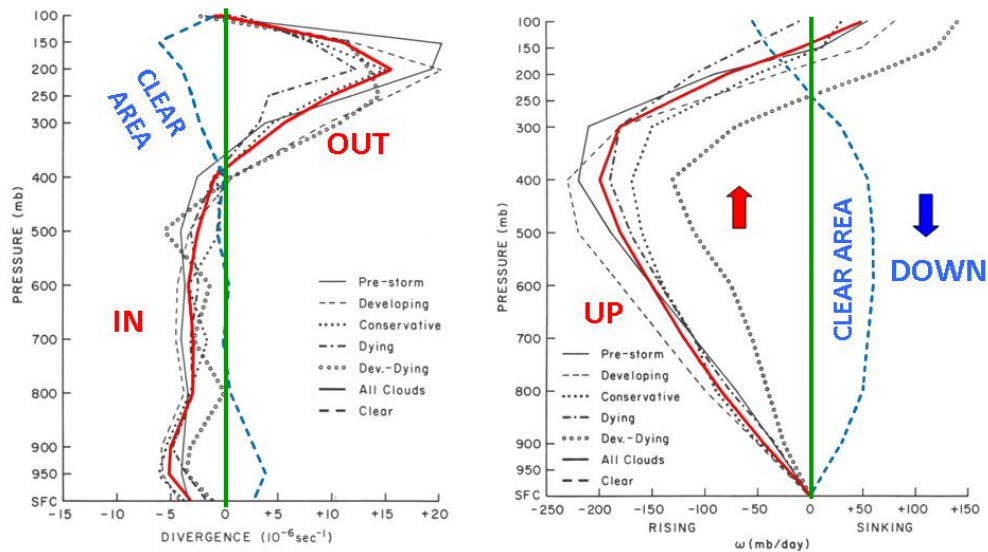


**Figure 11.3** – Research aircraft flight of US Nat. Hurricane Research Project of composited rain radar echoes on 6 September 1961, for developing Hurricane Carla (flight track in green). Maximum surface winds and minimum sea-level pressure at this time were about 30 m/s and 1000 mb respectively. Flight altitude was 990 m.

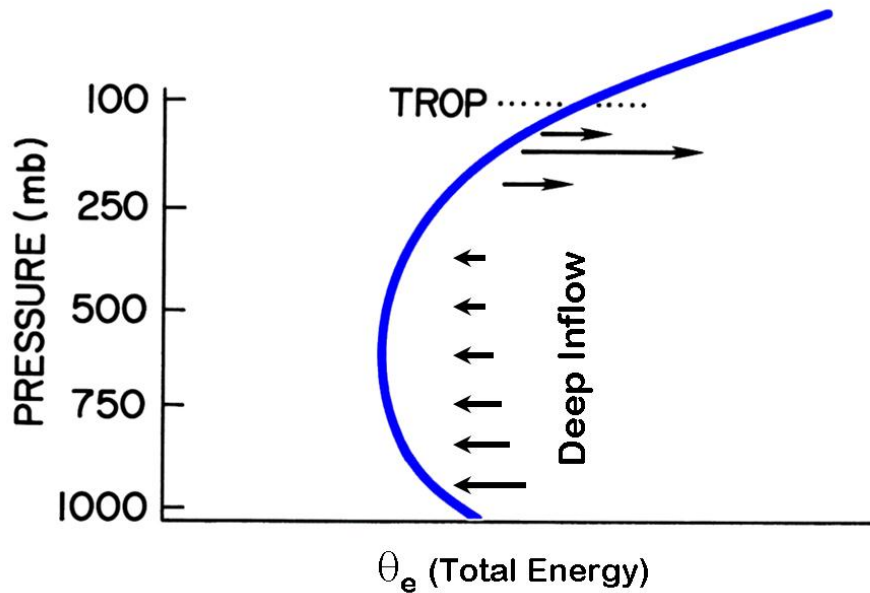
Figure 11.5 gives an illustration of the vertical variation of moist-static energy (that is  $h$  or  $\theta_e$ ) of the typical pre-TC cloud cluster. The mid-level inflowing air has the lowest  $\theta_e$  values. Most of this air acquires negative buoyancy and descends (except for the smaller portion that becomes entrained into the deep convective updrafts).

The up-and-downdraft recycling at the top of the PBL is fundamental to the accomplishment of the simultaneous mass, moisture, and energy budget of the average pre-TC cluster and hurricane. Downdraft rain-bands are a well known feature of the cloud cluster and the hurricane. This large up-and-down mass recycling is also a fundamental feature to allow the pre-TC and the hurricane to extract large amounts of energy from the ocean. This also allows for a large amount of high-level energy export. Such high level energy export is fundamental to the structure of the hurricane and cloud cluster.

Downdraft elements which penetrate into the PBL and push under the older and more unstable air of the PBL are necessary to mechanically force new updraft convective elements. These new PBL downdraft elements will, in time, also become 'recharged' through contact with the warmer (moist) ocean surface. They will then be able to be forced upward with their own higher temperature and moisture contents. They then become part of the newest deep convective cloud elements.



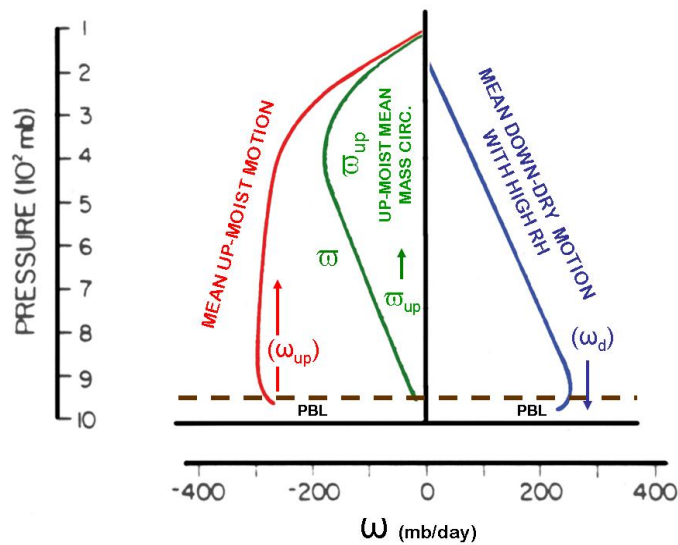
**Figure 11.4** – Vertical profiles of 0-4° radius area average rawinsonde composite divergence in  $10^{-6}s^{-1}$  (left diagram) and resulting mass balanced vertical motion (right diagram) in mb/day for a variety of cloud cluster types and a contrasting clear area for comparison (Williams and Gray, 1973). Note the uniform deep increasing mean vertical motion to the upper tropospheric in the average cluster (in red), the clear region deep subsidence (in blue). The general slope of these profiles is also applicable to the developed TCs. (Negative values of  $\omega$  mean upward motion, positive values indicate downward motion). Later rawinsonde compositing has well verified these typical profiles.



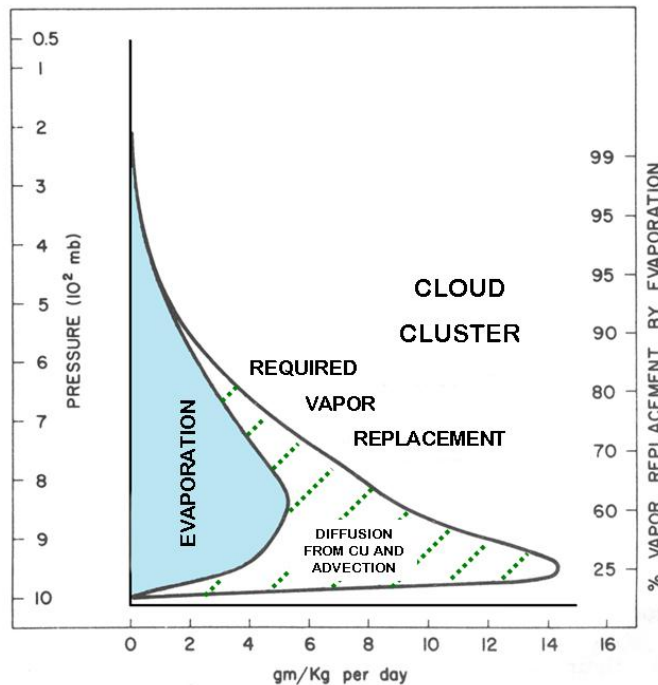
**Figure 11.5** – Vertical variation of the typical equivalent potential energy ( $\theta_e$ ) curve of the pre-TC cloud cluster that later becomes a hurricane. Note how the upper-level outflow occurs at a higher value of  $\theta_e$  than the inflow values. This in-and-out transverse circulation exports energy from the typical system. Also note how the lowest  $\theta_e$  values are advected into the system at middle levels. This low  $\theta_e$  inflow air is more able to feed downdrafts.

Figure 11.6 gives a vertical profile of the net required up-moist (red) and down-dry (blue) vertical motion in the 0-4° radius pre-TC cloud cluster which must be occurring in order that the pre-TC can simultaneously balance its mass, moisture and energy budget. Note that there is nearly 10 times as much up-moist and down-dry circulation at the top of the PBL as the mean upward circulation at this level. The mean upward moist circulation ( $\varpi_{up}$ ) can carry only about 30-40% of the required upward moisture flux. The other 60-70% of the upward flux is carried by the mass balancing up-moist minus down-dry circulation where the up-moist circulation carries about 5-15% higher moisture content than the downward dry (but high RH circulation) sinking motion at this level.

Figure 11.7 shows the needed steady-state moisture replacement by the sinking motion of the composite pre-TC cloud cluster. Vapor replacement occurs by evaporation and by cloud to cloud-free water vapor advection. This water vapor replacement is needed in order to maintain steady state moisture conditions. Note the required evaporation cooling rates of 4-5 gm/kg per day between 700 mb and 950 mb. This is equivalent to a rate of evaporative cooling of 9.6 to 12.0°C per day. These high evaporation and water vapor replacements rates are required to support the large amounts of drying resulting from such large amounts of cloud cluster downward mass subsidence.



**Figure 11.6** – Typical 0-4° radius required net up-moist ( $\omega_{up}$  - red and  $\bar{\omega}_{up}$  - green) and down-dry ( $\omega_d$  - blue) circulation of the typical tropical cloud cluster and pre-TC cluster. Note the large amount of up-and-down vertical circulation that is required at the top of the PBL to simultaneously satisfy mass, moisture, and energy requirements within the 0-4° radius. Observe that the mean upward vertical ( $\bar{\omega}_{up}$ ) motion is only about 3-4 cm/s or 30-40 mb/day while the total average upward motion at the top of the PBL is near 300 mb/d and the total average downward motion at this same level is about 260 mb/d.

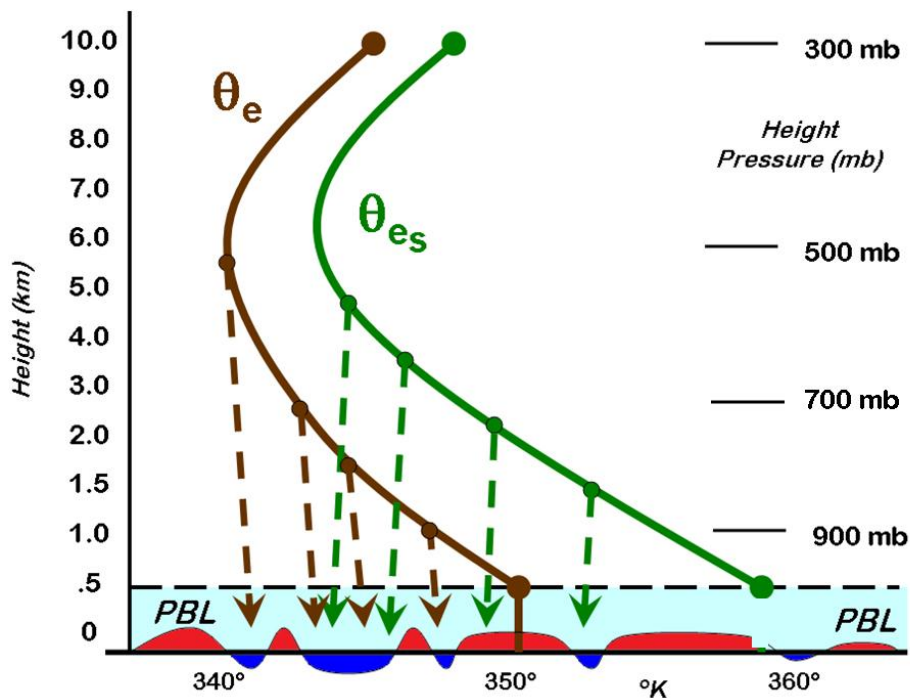


**Figure 11.7** – To maintain steady state moisture conditions within the pre-TC 0-4° radius meso-scale cloud cluster with the amount of up-moist and down-dry circulation of Figure 11.6, it is necessary that these amounts of vertical water vapor replacement occur to replace the sinking drying motion every day. The portion of vapor replacement coming from evaporation (blue) and the portion from diffusion-advection (dashed green) are differentiated. For every gm/kg of required cloud-drop evaporation there is a cooling of 2.4°C. Diffusion vapor replacement occurs when saturated cloud air or high RH are advected into the subsiding sub-saturated areas.

Figure 11.8 illustrates how it is possible to generate very large negative buoyancy for air parcels originating from the middle troposphere with liquid water evaporating into them such that they can sink very close to the moist adiabatically lapse-rate. Table 11.1 shows how negatively buoyant saturated downdraft middle troposphere air can be in comparison to PBL air. For instance, a cloud cluster air parcel that was saturated at 600 mb at the typical 600 mb temperature would have a saturated value of  $\theta_{es}$  that was 16°K lower than the  $\theta_{es}$  of the PBL. This gives a very high negative buoyancy potential to middle tropospheric air undergoing evaporation cooling at a rate which keeps them close to saturation.

**Table 11.1** – Vertical tabulation of the typical middle-level  $\theta_{es}$  values of the pre-TC cloud cluster and the high potential which middle-level air has to descend as downdrafts into the PBL when they undergo enough evaporation and water loading. Middle-level saturated air has substantially lower  $\theta_{es}$  air than does saturated PBL air and can develop large negative buoyancy. This negative buoyancy can generate strong middle-level downdrafts. These downdrafts can continue even if they lose full saturation at lower levels. They can compensate for any lack of low-level negative buoyancy with their downward momentum and overshoot into the PBL.

LEVEL in mb (km)	$\theta_{es}$ (°K)	$\Delta\theta_{es}$ Neg. Buoyancy
300 (9.7)	348	300 mb – PBL $\theta_{es}$ = - 9
400 (7.6)	347	400 mb – PBL $\theta_{es}$ = - 13
500 (5.9)	345	500 mb – PBL $\theta_{es}$ = - 15
600 (4.4)	344	600 mb – PBL $\theta_{es}$ = - 16
700 (3.1)	348	700 mb – PBL $\theta_{es}$ = - 12
800 (2.0)	351	800 mb – PBL $\theta_{es}$ = - 9
850 (1.5)	353	850 mb – PBL $\theta_{es}$ = - 7
900 (1.0)	355	900 mb – PBL $\theta_{es}$ = - 5
950 (0.5)	358	950 mb – PBL $\theta_{es}$ = - 2
PBL	360	



**Figure 11.8** – Illustration of the negative buoyancy and downdraft action which can develop from the sub-saturated inflowing air of cloud clusters which have converging air above the PBL and which experience strong evaporative cooling from falling rain.  $\theta_e$  is equivalent potential energy and  $\theta_{es}$  is saturated equivalent potential energy. These evaporative cooled downdrafts develop negative buoyancy and then sink into the PBL to undercut and mechanically force upward new convection units that have previously been ‘recharged’ from ocean influence. These new downdraft elements then gradually become ‘recharged’. Once ‘recharged’ these downdrafts are then able to rise as new deep convective elements when they themselves are undercut by yet newer downdrafts. PBL air that is warmer-moister (red) can spawn new updrafts while downdraft-induced cooler-drier air (blue) must be ‘recharged’ before it can rise. Downdrafts that become saturated or nearly saturated have large downdraft buoyancy.

These evaporative-cooled downdrafts which sink into the PLB bring about a large mass convergence which can only be compensated by an opposite mechanically forced upward fluxing of warmer and moister ‘recharged’ PBL air. This occurs during the period in which the recently arrived PBL downdraft air is undercutting the PBL’s already ‘recharged’ air to mechanically drive the formation of new up-moist convective elements (Figure 11.9). This ‘recharge’ of PBL air is accomplished by virtue of the large energy difference between the newly arrived cool and less moist downdraft air and the warm (and saturated) ocean. Exchanges occur through the bulk formula approximations, such as:

$$\text{Evaporation} = C_E \rho |V| (q_s - q_a)$$

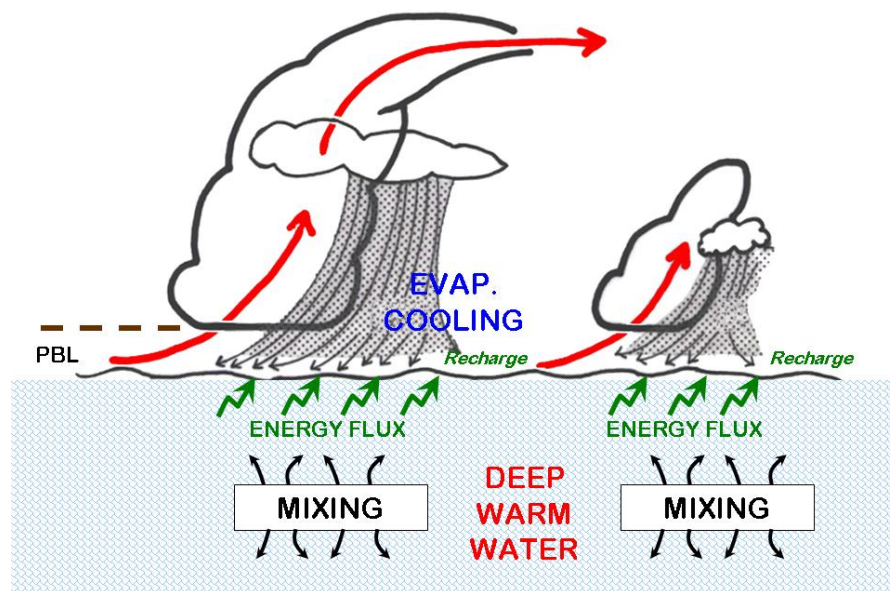
$$\text{Heat} = C_h \rho / C_p |V| (T_s - T_a)$$

$$\text{Momentum} = K (V_d - V_e)$$

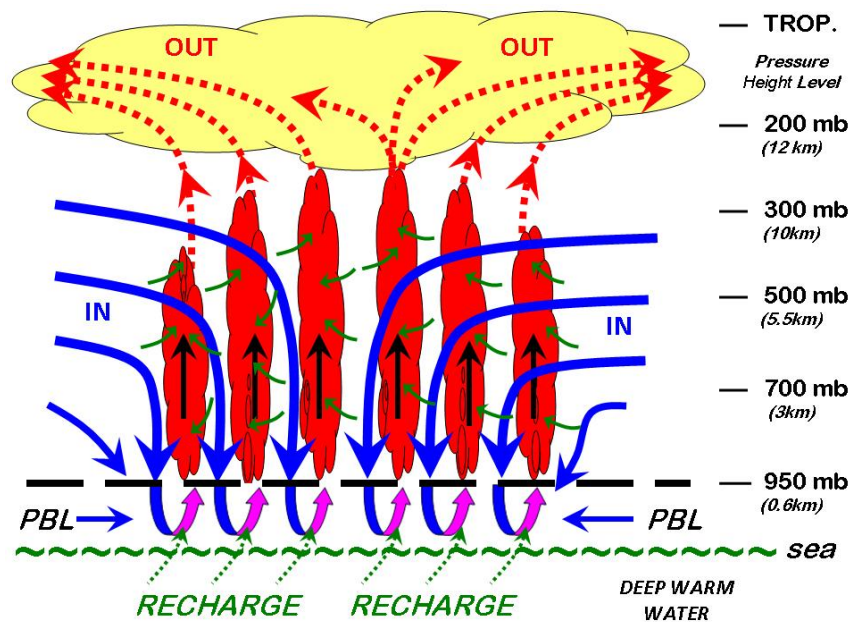
where,  $s$  stands for the sea,  $a$  for air 10 m above the sea,  $\rho$  for air density,  $q$  for specific humidity in gm/kg,  $C_p$  is the coefficient of heat exchange at constant pressure, and  $V_d$  for the horizontal velocity of the downdraft air over the mean 10 m environmental wind ( $V_e$ ).

To maintain themselves cloud clusters and TCs must extract large quantities of energy from the ocean. This requires that the ocean underneath the TC have been previously warmed with water above at least 26°C to a deep level of at least 50-100 m. The central area of intense TCs typically weakens when they move over deep water that is cooler. Similar weakening occurs when TCs slow or stall over shallow warm water and thus, upwell cold water near their centers. TCs also rapidly weaken when they move over land where the ocean energy source is no longer available.

Figure 11.10 illustrates the typical complex up-and-down vertical motion within the pre-TC cloud cluster and the developed hurricane. This figure illustrates the fundamental requirement for extensive downdraft mass penetration into the PBL and the great need for very large amounts of up-and-down mass recycled at the top of the PBL.



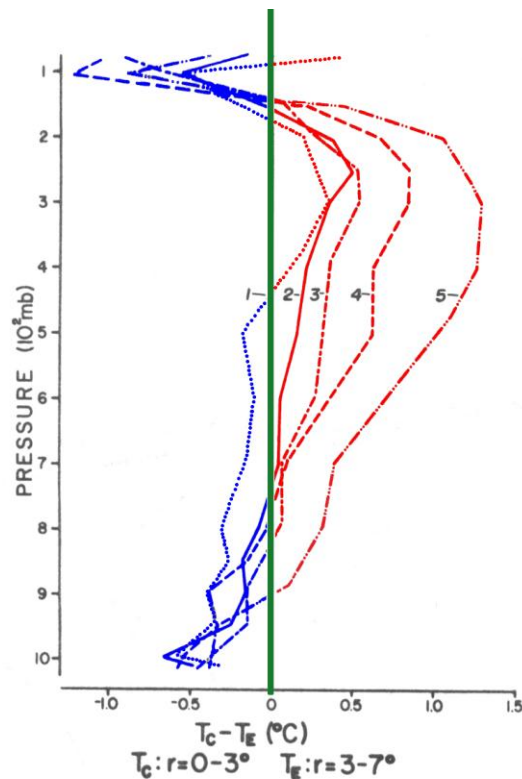
**Figure 11.9** – Idealized vertical cross-section of how downdrafts from stationary or squall-line convection can bring high momentum and cool-drier air into the PBL. The recharging of this cooler-drier downdraft air greatly enhances ocean energy extraction. The newly arriving downdrafts also serve as an undercutting mass source for new mechanically-forced updrafts that have already been recharged.



**Figure 11.10** – Idealized representation of the large amount of up (red)-and-down(blue) vertical motion which must take place in the pre-TC disturbance and in the developed hurricane in order to maintain their simultaneous mass, energy, and moisture budgets. The green solid arrows represent entrainment into deep cumulus updrafts (15-20% of middle-level inflow air). The blue arrows represent the inflowing middle-tropospheric mass (80-85%) going into the negatively buoyant downdrafts. The ocean ‘recharge’ of the cooler-drier downdraft air is necessary to mechanically force the prior downdraft air that has already been recharged upward to develop updraft new deep convective elements. The ocean ‘recharge’ is also a requirement for the clusters large sea to air energy fluxes. Such large sea to air energy fluxes allows the system to be a net horizontal export of energy.

In terms of TC intensity, it is more important to have deep warm ocean water extend to 50-100 meters depth than to have somewhat warmer but shallower SST conditions. Hurricanes upwell and turbulently mix ocean water from depths of 50-100 meters to near the surface. Strongest upwelling is concentrated around the cyclone’s center. This water then spreads outward to broader areas. There is also another type of turbulent mixing of underneath colder water to the surface at larger radius.

TCs typically leave trails of cooler water in their wakes. For instance, cooler water is found as a result of the upward mixing of ocean water in areas that hurricanes have recently moved over. This is especially the case if there is not a deep residue of warm water. Too much upwelling and mixing of deep colder water within the TC PBL reduces the cyclone’s ability to ‘recharge’ the downdraft air penetrating into its PBL. This will inhibit the maintenance of the necessary convective units needed to keep the large required potential energy export of the TCs upper tropospheric outflow. To maintain a TC’s intensity it is usually necessary that it move at a rate of at least 10-12 mph so as to be able to continuously have new deep warm water underneath it. All TCs cool large amounts of warm water and leave behind cooler water in their wakes.



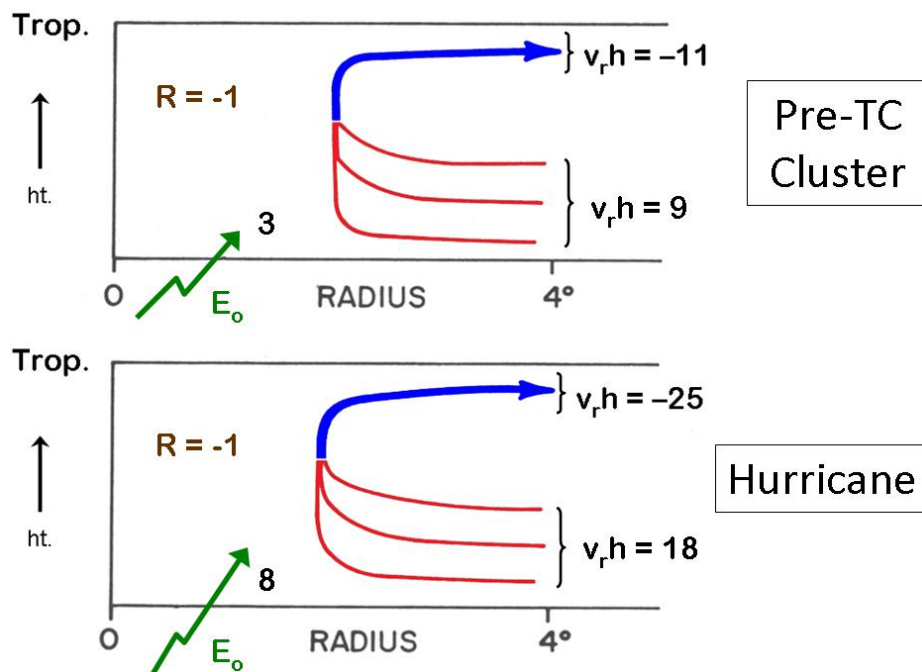
**Figure 11.11** – Vertical rawinsonde composite of the difference in the variation of  $(0-3)^{\circ} - (3-7)^{\circ}$  radius temperature anomaly. Increasing numbers imply an increasing intensity (1 to 5) of a developing TC. Note the inner-region cooling below 900 mb which is a result of the as yet uncompensated cooling from cool downdrafts into the PBL and the low-level frictionally driven Ekman and meso-scale inflow expansion to lower pressure cooling in the PBL (Zehr, 1976) without full sea to air sensible heat compensation. Note how inner-core lapse-rates grow in vertical temperature stabilization as TC intensification proceeds.

**COOL PBL AND DECREASING LAPSE-RATES OF DEVELOPING TROPICAL CYCLONES.** Figure 11.11 portrays rawinsonde composite vertical differences in temperature between  $0-3^{\circ}$  radius minus  $3-7^{\circ}$  radius for ever increasing states (1 to 5) of West Pacific developing TCs (Zehr, 1976). Note that the temperature from  $0-3^{\circ}$  radius in the PBL of these developing TCs can be  $1-3^{\circ}\text{C}$  colder than the cyclone's environmental temperature at  $3-7^{\circ}$  radius in the PBL. By contrast, the upper-level temperature of the inner-core is higher than that of the environment. This inner PBL cooling is hypothesized to be due to two primary factors:

1. The inner-area cool downdraft air from the deep convective element which spreads out in the PBL and has not yet had time to be recharged. The outer  $3-7^{\circ}$  radius area has no such downdraft cooling.
2. The expansion cooling of the down-pressure gradient frictional and meso-scale inflow-driven air within the PBL that has not yet been fully compensated by surface to air sensible temperature flux.

The upper tropospheric warming is due to the mass balancing up-moist and down-dry vertical circulation within  $0-3^\circ$  radius. This causes the upper tropospheric warming that is typical of all developing and developed TC systems. Note also that the lapse-rates of the inner-core are reduced from the lapse-rates of the outer fringes of the cyclone. It is possible to increase a TC's inner-core deep convection as lapse-rates become more stable. Some inner-core lapse-rates become absolutely stable and convection occurs by the updraft sloping to cooler air (slope convection). This often occurs in the eye-wall cloud (Eastin *et al.*, 2005 I & II). Small changes of environmental SST of less than  $1^\circ\text{C}$  would likely not play much of a role in these strong inner-core exchanges.

**THE TROPICAL CYCLONE ENERGY BUDGET.** Tropical cyclones export more total ( $\theta_e$ ) or moist-static energy ( $h$ ) in their upper level outflows than they import in their low and middle-level tropospheric inflows (see Figure 11.12). TCs can maintain themselves only if they gain more heat and moisture energy from their underlying ocean surface than they export through their net in-and-out transverse circulation. Upper-level energy exports occur primarily as potential energy. Extra surface energy is also needed to balance the system's tropospheric radiational cooling.



**Figure 11.12** – Schematic representation of the typical  $h$  or moist static energy budget [ $\theta_e = 1/C_p (gZ + C_p T + Lq)$ ] within  $0-4^\circ$  radius of the steady-state cloud cluster, (a), and of the steady state hurricane, (b).  $E_o$  is the ocean to air energy flux and  $v_r$  the radial wind speed. Assuming  $-1$  unit (or  $-1^\circ\text{C}$  mean tropospheric radiational cooling per day) the cloud cluster evaporation plus sensible heat energy flux rate is three times the radiational loss. This gives a typical pre-TC cluster average evaporation rate of  $0.8$  cm/day. The energy of sensible heat flux is assumed to be half that of the evaporation rate. The hurricane evaporation rate is estimated to be three times the cluster rate or  $2.4$  cm/day (adapted Gray, 1979 and Frank, 1977b). Both systems export more energy in their upper-level outflow than they import below. The difference being made up by enhanced surface energy flux.

Note in the bottom diagram of Figure 11.12 that well developed hurricanes export much more energy in their outflows than do early stage pre-TC cloud clusters. The higher and stronger the TC's outflow level the larger is its export of energy. The more intense the cyclone, the larger the quantity of energy it must extract from the ocean. This is one of the limiting factors on the TC's maximum intensity.

The amount of energy TCs can extract from the ocean does not have a high correlation with the prior environmental SST over which the cyclone moves or with the lapse-rate potential buoyancy within or immediately surrounding the Cb convection. Other factors also play important roles.

The higher the cyclone's outflow, the higher the TC vortex extends in the vertical, and the higher in the troposphere the required inner area warming will occur to sustain the cyclone's central pressure drop. Due to the enlargement of the  $(\delta p/p)$  coefficient with height in the thickness equation  $[\Delta Z = R/g(T\delta p/p)]$ , it is readily shown that more central pressure decrease in the TC can be obtained for a given unit of warming if this warming is placed as high as possible in the troposphere. The more energy that the TC can extract from the ocean underneath it, the higher can be the cyclone's outflow level and the greater can be the cyclone's pressure decrease for a given amount of warming.

**SUMMARY.** There is no question that convective downdrafts are crucial to the structure of the cloud cluster and the hurricane. There is likely a close range of middle tropospheric relative humidity, Cb convection, and downdraft frequency and strength within the pre-TC cloud cluster and the hurricane which lead to the optimum conditions for system intensification, its steady-state, and its weakening. Optimum conditions would lead to intensification with less optimum conditions to steady-state and still less favorable conditions to weaken. Optimum conditions may occur between the following two different arrangements of RH and numbers of updrafts and downdrafts:

1. When middle-level RH values are higher than optimum there is a less restrictive entrainment environment that favors Cb elements. Higher mid-level moisture allows for too little evaporational cooling and not enough downdraft action. There is not enough mass flux into the PBL to replenish the needed new convective updrafts.
2. When middle-level RH values are lower than optimum, there are higher and stronger entrainment rates and a consequent restriction in deepest Cb convection. An enhancement of evaporation cooling and downdraft strength also occurs. Too much downdraft mass would penetrate into the PBL. The PBL would then not be able to 'recharge' its downdrafts air fast enough to be able to produce enough warm and moist unstable convection air. This would not allow the extra upward mass forcing of wider-and-stronger convective element coming out of the PBL that would be required to overcome the higher inhibiting entrainment of the dryer middle-level air. Cloud cluster and developed TC intensity are observed to fluctuate back and forth between these different relative states.

The influence of middle-level RH variations is very important. More study of its influence on weather systems is needed. There is not a strong day-to-day correlation of middle-level moisture with SST and lapse-rates.

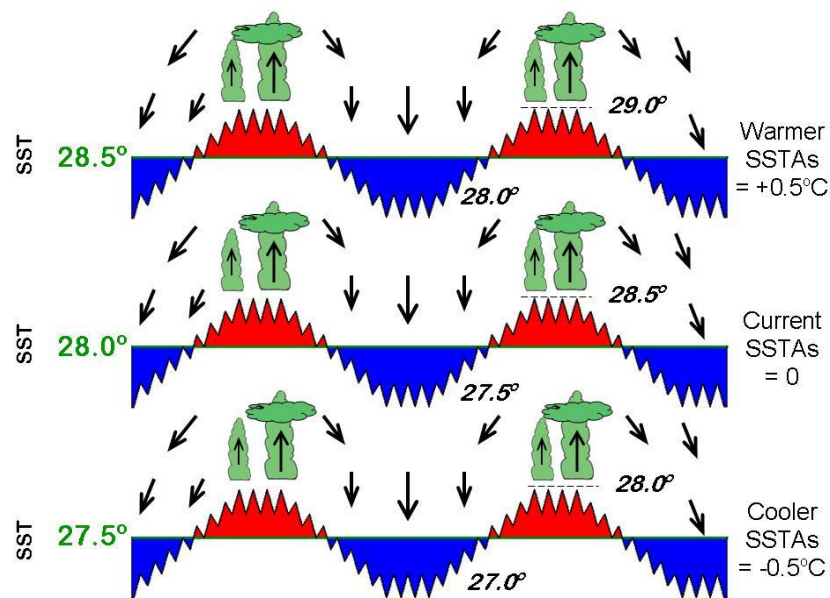
## **12. GLOBAL RAINFALL'S STIMULATION OF RADIATION ENERGY TO SPACE (IMPLICATIONS FOR CLIMATE PREDICTION AND GLOBAL WARMING)**

**THE CONCENTRATED NATURE OF GLOBAL RAINFALL.** Precipitation is a fundamental component of the global and the tropical energy budgets. Global energy budget requirements dictate that every day slightly less than 0.3 cm of global average precipitation occurs (or about 1 m/yr). Of this, about 0.4 cm/d average precipitation must occur within the tropics (30°N-30°S) and about 0.2 cm/d average precipitation occurs in the middle-latitude and polar regions (> 30° latitude).

Most global precipitation (approximately two-thirds) occurs in concentrated Cb and/or towering cumulus convective clouds. If we assume that the average deep cumulus cloud produces rainfall at a modest average rate of 1 cm/hour, then all these convective clouds, at any one time, would cover only about one percent of the globe's surface. All of the upward mass flux associated with these concentrated deep convective clouds which extend into the upper-half of the troposphere must be balanced by a return flow mass sinking over the remaining 99 percent of the globe. This return flow subsidence originates from higher and colder levels where the air holds little water vapor. As this dry air descends and spreads out at lower levels, it brings its low moisture content air with it. The typical low relative humidities (RH) of the globe's upper and middle tropospheric air (~20-50 percent) attests to the importance of this broad-scale subsidence drying in response to the globe's rainfall.

Most of the globe's 'daily average' rainfall is concentrated in selective areas covering no more than 4-6 percent of the globe's surface where about 3 cm/day (or 1.2 inches/day) of rainfall occurs. It is from such organized meso-scale rain areas of the warmer portions of the oceanic tropics that TCs form (Figure 12.1).

Most tropical rainfall is concentrated in localized meso-scale (250-500 km) areas of groups of deep convective units between broad scattered cloud and clear regions of weak subsidence air. The subsidence areas between rain areas cause the upper and middle tropospheric levels to be strongly sub-saturated. The more rain that occurs in these restrictive rain areas the more upward vertical motion and the more mass balancing subsidence there is (and the lower are the RH values) in the non-rain areas. This keeps the broad upper tropospheric IR radiation emission level from becoming more elevated and cooler as rainfall increases. More rainfall can thus lead to an IR (or OLR) radiative emission level being lowered to a slightly warmer level (due to upper tropospheric water vapor reduction) in the broader subsidence areas. This allows for a higher rate of IR (or OLR) radiation to be emitted ( $\sigma T^4$ ) to space even though net rainfall rates and net precipitable water amounts over the whole tropics or over the globe may have increased.



**Figure 12.1** – Illustration of how the mean SST climatology of the summertime tropics (30°N-30°S; 0-360°) might rise or fall by 0.5°C from the middle diagram (28°C) but the potential lapse-rates for deep Cb convection in the TC basins (red areas) are not significantly altered. SST changes over the whole tropics are different from local region SST changes. As the global temperature increases or decreases, we should expect all relative warmer and colder areas to increase in unison and vertical lapse-rates in these areas to also increase or decrease in unison. Lapse-rates and rainfall rates should be little affected.

The author and his colleague, B. Schwartz, through extensive analysis of NOAA-NCEP reanalysis data and International Satellite Cloud Climatology Project (ISCCP) satellite products find that when tropical and global rainfall rates are increased by a few percent, there is typically a corresponding small increase in net radiation energy to space. Both IR and albedo radiation flux to space become, in combination, typically larger by an amount about equal to the energy required for the enhanced surface evaporation (Gray and Schwartz, 2011).

Our measurements do not agree with the conclusions of the 19 IPCC-AR4 GCM simulations which are all in close agreement in showing a strong positive rainfall-water vapor enhanced warming feedback of 2°C with their climate simulations of the influence of a doubling of CO<sub>2</sub>. These GCM warming scenarios appear to have greatly exaggerated the influence of CO<sub>2</sub> warming by a factor of as much as 5 to 10 due to their assumption that upper-level water vapor will increase as rainfall rates increase – the so called ‘positive water vapor feedback’. Our data analysis does not support this crucial but flawed assumption.

**LITTLE POTENTIAL INFLUENCE OF CO<sub>2</sub> ON GLOBAL TC ACTIVITY.** Even though CO<sub>2</sub>, methane, and other smaller trace gases are designated greenhouse gases (similar to water vapor), they act in very different ways from the atmosphere’s primary greenhouse gas of water vapor. Water vapor continuously rains out of the troposphere at a rate of about 10 percent per day. It totally replaces itself in the atmosphere every 10 days. Water vapor is quite variable by location, altitude, and time of year. The surface evaporation necessary for the troposphere’s rapid water vapor replacement acts as the globe’s primary coolant to balance the earth surface’s large average solar energy absorption of 171 Wm<sup>-2</sup>.

Figure 12.2 portrays the globe's annual energy budget. Note that the earth's surface absorbs about half ( $171$  of  $342 \text{ Wm}^{-2}$ ) of all the solar energy which impinges upon the earth. The globe's surface evaporation rate balances about half ( $85$  of  $171 \text{ Wm}^{-2}$ ) of the solar energy which the earth absorbs. The other half ( $\sim 86 \text{ Wm}^{-2}$ ) is balanced by surface upward IR flux and sensible heat flux to the air above. Energy is lost from the surface through the conversion of liquid water to vapor. It takes  $290 \text{ Wm}^{-2}$  of solar energy for each  $\text{gram/cm}^2$  per day of water which is evaporated.

I hypothesize that when  $\text{CO}_2$  amounts double near the end of this century and there becomes a blockage of IR energy to space of  $3.7 \text{ Wm}^{-2}$ , the global system will adjust to this  $3.7 \text{ Wm}^{-2}$  IR blockage in about the same relative ratios as it does with the total energy budget today. We would thus see (Figure 12.3) a global rainfall increase of about  $1.8 \text{ Wm}^{-2}$  (or  $85$  to  $86.8 \text{ Wm}^{-2}$ ), a surface enhanced upward IR flux increase of  $1.3 \text{ Wm}^{-2}$  (or  $59$  to  $60.3 \text{ Wm}^{-2}$ ) and a surface to air increase of sensible heat upward flux of  $0.6 \text{ Wm}^{-2}$  (or  $27$  to  $27.6 \text{ Wm}^{-2}$ ). These changes would cause an increase of global average rainfall of about  $2.1\%$  and an increase of global mean surface temperature of about  $0.3^\circ\text{C}$ . This warming is only about  $10\text{-}15$  percent as much as the GCMs have been projecting. This amount of warming should not raise alarm.

Although the net water vapor in the troposphere (or precipitable water) may go up a little as rainfall increases, the water vapor content in the upper troposphere is expected to slightly decrease with enhanced global rainfall. The tropics and the globe's average radiation emission level of IR (or OLR) to space are expected to be somewhat lowered during global rainfall enhancement. This will allow for more IR flux to space. There are also slightly higher amounts of albedo energy loss to space with higher rates of global and/or tropical rainfall.

It is important to separate the atmosphere's 'dominant' and 'active' greenhouse gas of water vapor from the more minor and inert greenhouse gases of  $\text{CO}_2$ , methane, etc. Although the globe's net precipitable water in the troposphere may rise a bit during periods of enhanced global rainfall, the water vapor in the upper troposphere is observed to slightly decrease and the net radiation energy to space (IR + albedo) increase by small amounts when global and/or tropical rainfall is increased by a few percent. The reverse also occurs. Energy to space typically decreases by a few percent when global and/or tropical rainfall is decreased by a similar percentage.

Figure 12.4 graphically illustrates how a slight lowering of the IR emission level of  $1^\circ\text{C}$ , due to enhanced global rainfall, would lead to about a  $3.5 \text{ Wm}^{-2}$  enhancement of OLR to space and, all other factors being constant, a small cooling of the troposphere in response. Figure 12.5 illustrates our concept of the basic difference between the net-radiation to space which occurs when deep precipitation is increased (top diagram) and the opposite concept that the GCMers and most scientists have when global rainfall is increased (bottom diagram). The GCM modelers believe that increased rainfall leads to increases in upper-tropospheric water vapor and that this increased water vapor adds additional blockage of OLR to space. From our extensive analysis of the reanalysis and ISCCP data sets we are finding the opposite.

Unlike the ocean, the atmosphere does not have the capacity to store energy. The atmosphere's equilibrium state is determined by the amount of energy which is impinged upon

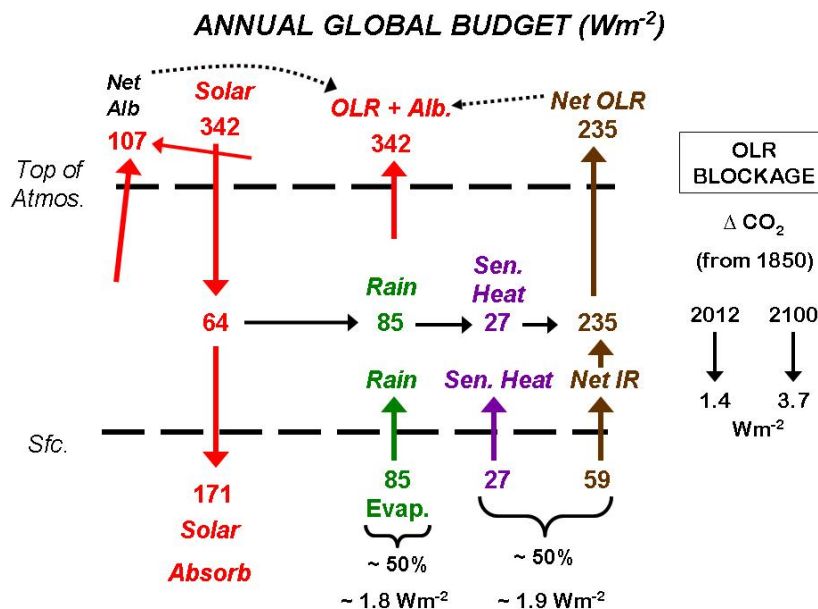
it. A high impingement of energy to the atmosphere would require that it adjust to this large energy gain by developing an export mechanism (radiation or water change of state) that rises just enough so as to balance most of this impinged energy gain. The opposite should occur when the atmosphere cools.

We assume that a  $3.7 \text{ Wm}^{-2}$  blockage of OLR from the doubling of  $\text{CO}_2$  would, in time, be able to develop a new equilibrium state for the global system that is only about  $0.3^\circ\text{C}$  warmer than before the industrial revolution. This amount of warming would not bring climate degradation.

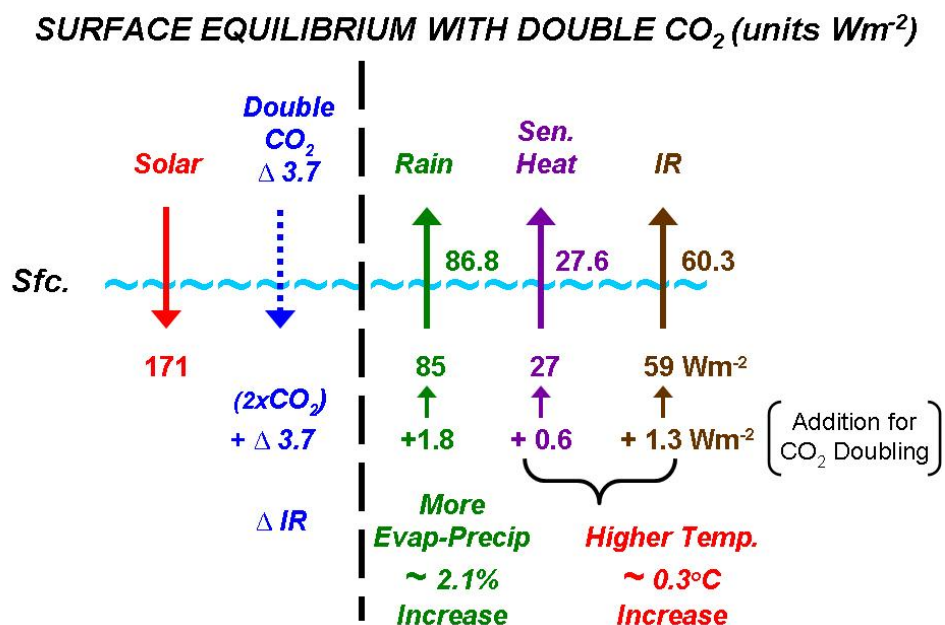
This analysis would also argue against a significant solar activity influence on global climate and on TC activity. Sun spots, cosmic rays, and other types of solar variability are just too small in magnitude to compare with the influences of a doubling of  $\text{CO}_2$ . Here I agree with the modelers.

**TROPICAL CYCLONE INFLUENCE ON THE GLOBAL RAINFALL BUDGET.** Accepting the fact that most (75%) of the globe's rainfall (the other 25% being sensible heat flux) occurs primarily as an up-moist and down-dry warming response to balance the troposphere's radiational cooling, one can ask: to what extent does TC rainfall contribute to the overall global rainfall balance?

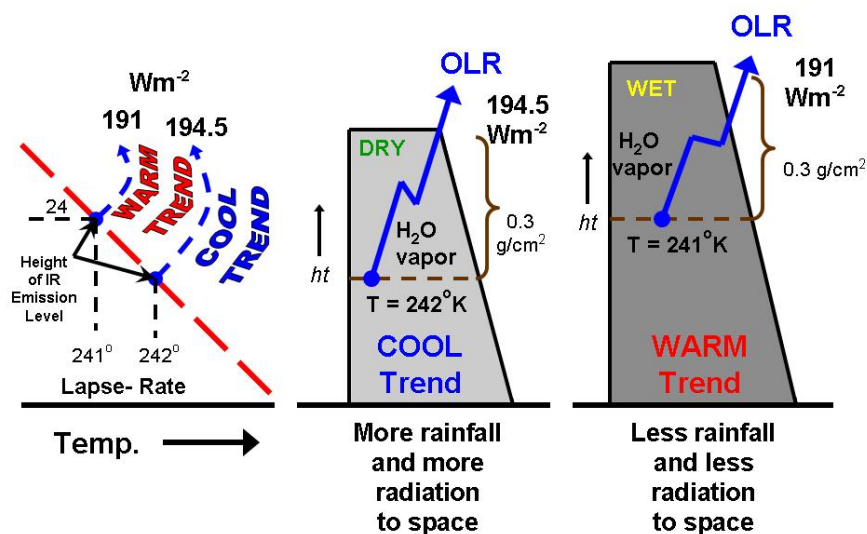
Global TC activity is least frequent during April and May when the sensible heat transport from the Eurasian and North American continental land areas is at a yearly maximum and less rainfall is needed to balance tropospheric radiational loss. Surface evaporation and rainfall are reduced during this period. TC activity is at a maximum in August through October when land to air sensible heat transport is reduced, and lapse-rate stability over land is reduced due to the seasonal lag of upper air cooling behind surface land cooling. Overland convective rainfall is reduced in late summer and autumn. More of the global rainfall must then come from organized weather systems such as TCs as a compensation for reduced land lapse-rates and precipitation.



**Figure 12.2** – Vertical cross-section of the annual global energy budget as determined from a combination of ISCCP and NCEP reanalysis data over the period of 1984-2004. Note on the right, how small is the OLR (or IR) blockage that has occurred up to now due to CO<sub>2</sub> increases ( $\sim 1.4 \text{ Wm}^{-2}$ ) and how relatively small is the blockage of  $3.7 \text{ Wm}^{-2}$  that is estimated to occur when a doubling of CO<sub>2</sub> occurs by the end of this century. Compare these small CO<sub>2</sub> induced IR changes in  $\text{Wm}^{-2}$  to the global average solar impingement of  $342 \text{ Wm}^{-2}$  of incoming energy,  $235 \text{ Wm}^{-2}$  of outgoing OLR,  $107 \text{ Wm}^{-2}$  of outgoing albedo flux, and  $171 \text{ Wm}^{-2}$  of surface solar absorption.

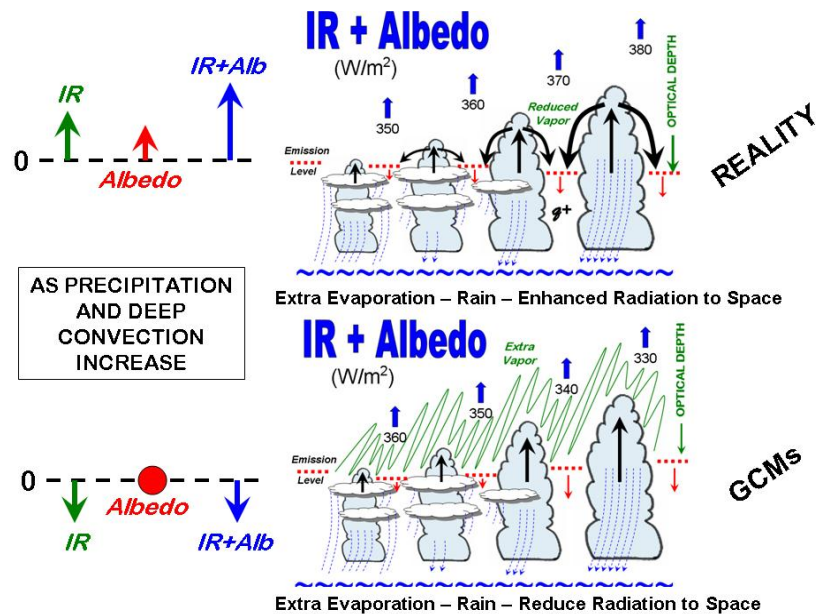


**Figure 12.3** – Estimated change at the surface of global mean rainfall (2.1% increase) and global mean temperature ( $\sim 0.3^\circ\text{C}$ ) when, and if, equilibrium energy balance were even established for a doubling of CO<sub>2</sub> (and a blockage of IR energy to space of  $3.7 \text{ Wm}^{-2}$ ).



**Figure 12.4** – Greatly exaggerated illustration of how lowering of upper-level water vapor (and the IR emission level) from  $241^\circ\text{K}$  (right) to  $242^\circ\text{K}$  (left) increases OLR by  $3.5 \text{ Wm}^{-2}$  due to enhanced radiation

( $\sigma T^4$ ). Deeper and more intense convection, more upper-level mass subsidence, and a lowering of the emission level (left area) is hypothesized to let more OLR to space and lead to a cooling trend. The opposite occurs in the right area. The greater rainfall would also lead to a slightly higher albedo and yet more radiation to space.



**Figure 12.5** – Two contrasting views of the effects of how the continuous intensification of deep cumulus convection would act to alter radiation flux to space. The top diagram emphasizes the increasing extra mass flow return subsidence associated with an ever increasing depth and intensity of cumulus convection. Radiation flux to space increases with enhanced deep convection and rainfall due to a lowering of the upper-level emission level and an increase in albedo. By contrast, the bottom diagram interprets the increase of deep convection (like the GCMs have done) as acting to add moisture to the upper tropospheric levels and cause a decrease of radiation to space. The bottom diagram is not realistic and a primary reason why the GCMs exaggerate CO<sub>2</sub>'s influence on global warming.

W. Frank (1977) has estimated that the mean precipitation within 6° radius of the average west Pacific tropical cyclone whose central pressure is <980 mb is ~2.3 cm/d. Most TC precipitation occurs within 6° radius. As west Pacific cyclones are typically larger, and produce somewhat more rainfall than those of other regions, it will be assumed that the average global TC (0-6° radius) has a mean precipitation of about two-thirds of this amount, or ~1.5 cm/d. This is five times the amount of global average precipitation.

Assuming that the global average annual precipitation is ~1 m/year, that the average cyclone maintains its rainfall for about one week, and that there are about 75 global named storms per year, one can estimate that TCs account for about 2 percent (1.5 cm/day x 7 days x 75 x ( $A_{\text{cyclone}}/100 \text{ cm } A_{\text{globe}}$ )) of the global annual precipitation. During August and September they probably account for about 4-5 percent of the global precipitation while during April and May only about 0.5-1 percent. During especially active 10-20 day periods in August and September, TCs may account for as much as 10-15 percent of the global precipitation and 20-30 percent of northern hemisphere precipitation. Thus, at selective times of the year, the influence of the TC is likely to be a significant component of the day to day maintenance of the global water

budget. For the long-term point of view, however, the condensation energy contribution of TCs does not appear to be a primary component of the tropospheric water budget.

If TCs are responsible for about 2 percent of the global annual rainfall ( $\sim 85 \text{ Wm}^{-2}$ ) and the doubling of  $\text{CO}_2$  will bring about 2 percent additional global TC rainfall, then we can estimate that a doubling of  $\text{CO}_2$  would cause global annual TC activity to bring about  $(.02 \times .02) = .0004$  or about 1/2500 of the globe's annual rainfall. Doubling of  $\text{CO}_2$  will have minimal influence on global TC rainfall. If this argument is valid then we could also conclude that  $\text{CO}_2$  doubling to have minimal influence on TC lapse-rates and net global TC activity.

Over the tropical oceans where TCs form, we should expect a higher percent of the blocked IR flux from a doubling of  $\text{CO}_2$  to go into enhanced evaporation (perhaps  $2.7 \text{ Wm}^{-2}$ ) with less into IR and sensible heat (perhaps  $1.0 \text{ Wm}^{-2}$ ). This implies that a doubling of  $\text{CO}_2$  would cause an increase in SST in the areas where TCs form of only  $0.1\text{-}0.2^\circ\text{C}$ .

**$\text{CO}_2$ -INDUCED CHANGES IN TC ACTIVITY.** We have no plausible physical reason for believing that global TC frequency or intensity will necessarily change to any significant degree if global SSTs were to rise or be lower by a small amount due to an excess or deficit of external (solar or infrared) energy impinging on the earth. For TC activity and SST changes to be strongly correlated, it would be necessary for other basic requirements for TC intensity and frequency to also be altered.

One would not expect the ocean to air energy fluxes to be much altered if SSTs in the tropical formation regions were somewhat higher or somewhat lower than average. Small global SST increases or reductions of  $\pm 0.5^\circ\text{C}$  over long decadal or century time periods should not have much of an influence on the frequency and/or intensity of global TC activity (Figure 12.1).

Although the existence of conditionally unstable lapse-rates are required for the presence of Cb convection, such lapse-rate buoyancy is not the only needed component for the maintenance of organized tropical cloud clusters and developed hurricanes. Very similar vertical lapse-rate temperature conditions exist in nearly all pre-cyclone cloud clusters and also in the broad lower latitude party-cloudy and clear regions. It is often the middle-level moisture which most distinguishes the cloud clusters which become TCs from those which do not. Temperature lapse-rate conditions are usually not a significant element in determining the existence and the intensity of Cb convective elements or of the amount of mass which the cloud cluster carries into the upper troposphere. Other factors such as downdraft strength and frequency, outer radius wind surge action, establishment of banded deep convection, etc. can often play more dominant roles.

Evidence from historical and paleo climate records appear to indicate that hurricanes of the Atlantic or typhoons of the Northwest Pacific were not necessarily less intense during the Little Ice Age when tropical SSTs were likely somewhat cooler.

For the development of the most intense hurricanes and typhoons it is necessary that many other features besides SST and conditionally unstable lapse-rate conditions be present. Other factors needed for maximum TC intensity include:

1. Depth of warm water over which the cyclone moves (primary element).
2. The moisture content of the mid-tropospheric air flowing into the disturbance.
3. The degree of horizontal wind blow-through (or ventilation) the cyclone system.
4. Character of the outer rain band structure and its variations.
5. Strength of the cyclone's outer low and middle-level cyclonic circulation and their changes with height and time.
6. Characteristics and strength of the hurricane's upper-level outflow circulation.
7. Speed and direction of the TC movement.
8. Changing dimensions of the eye-wall cloud and other bands.
9. Slope of the eye-wall cloud.
10. Etc.

One should not assume that small increases in SST or increases in lapse-rates would necessarily act to make variations in these many differing TC features to function in the direction of causing TCs to become more intense or more frequent.

### **WHY SKILLFUL LONG RANGE CLIMATE AND TROPICAL CYCLONE PREDICTION IS NOT POSSIBLE.**

Very skillful initial-value GCM forecasts for tropical cyclone climate will likely never be possible. This is due to the overly complex nature of the atmosphere-ocean-land system and the inability of numerical models to realistically represent this full range of this complexity and to integrate such a complex system forward in time for hundreds of thousands of time steps into the future. Skillful short-range prediction of 5-10 days is possible because there tends to be conservatism in the initial momentum-pressure fields which can be extrapolated or advected for short periods into the future. But beyond about 10-15 days, the many multiple unknown and non-linear energy and moisture exchanges within the earth system become dominant. Unexpected and unpredictable turbulent bursts occur that rearrange the large scale circulation patterns (Ramage, 1976). Model results soon decay into chaos. Any imperfect representations of the highly non-linear parameters of the atmosphere-ocean system tend to quickly undergo exponential growth (the so-called butterfly effect) and decay into unrealistic flow states upon a very long integration period.

If the climate prediction problem is treated as a boundary-value problem where only the future climate energy forcing components are predicted, different but no less tractable problems arise. For instance, besides the known and impossible to overcome 'butterfly' problems, there are known systematic errors in all the current GCMs. These systematic errors would also make the boundary value treatment of the climate prediction problem unrealistic. For instance:

1. The gross errors of the GCMs which are associated with their programmed strong positive water vapor feedback assumption. This causes the GCMs to give far too much global warming to their CO<sub>2</sub> doubling simulations. This is currently a major impediment to any type of realistic global simulation.

There is no way a CO<sub>2</sub> doubling by itself could ever bring about the amount of 2-5°C global warming the GCMs have been predicting over the last 20-25 years. Observations show that the assumption of constant relative humidity (RH) in the upper troposphere as global warming occurs is invalid. The Charney Report (1979) assumption that constant RH will accompany temperature increase (accepted by nearly all climate models) is not correct for the upper troposphere. Due to the unique character of the individual units of deep cumulus convection, upper-tropospheric RH in the tropics does not necessarily go up with increased global rainfall or increased upper tropospheric temperature. Measurements show that upper tropospheric RH has been going down since the mid-1970s despite some upper tropospheric global warming. And recent-year ISCCP data has indicated a small enhancement (not reduction) of IR radiation to space of 1-2 Wm<sup>-2</sup>.

I don't think any of the global modelers fully understand atmospheric moist processes, particularly the effect of deep Cb convection, to the extent that is necessary to be able to develop moist parameterization schemes realistic enough to be able to forecast future climate with any reliability. They are still not able to properly model or parameterize the strong sub-grid scale mass compensating up-moist and down-dry-and-moist processes of the troposphere.

2. The GCMs also do not include or are not able to properly model the decadal and century scale deep-ocean circulation changes which appear to be driven by ocean salinity variations. This includes the Meridional Overturning Circulation (MOC) of which the Atlantic Thermohaline Circulation (THC) is a fundamental component. These deep ocean circulation patterns have yet to be well understood and will require much study before they can be correctly included in the climate models. Modeling these ocean circulations requires the realistic prediction of variations in surface and deep-ocean salinity variations - a very difficult task which has yet to be satisfactorily incorporated in the GCMs.

If the GCMs are not able to produce a realistic basic future climate, how can we ever expect them to be able to realistically downscale these results to be able to realistically deal with future changes in the global sum of meso-scale events such as tropical cyclone frequency as well as TC intensity changes? There are a growing number of papers showing that downscaling from global model runs to determine regional climate changes does not show reliable skill. This is, of course, to be expected if the GCM from which the downscaling occurs is invalid.

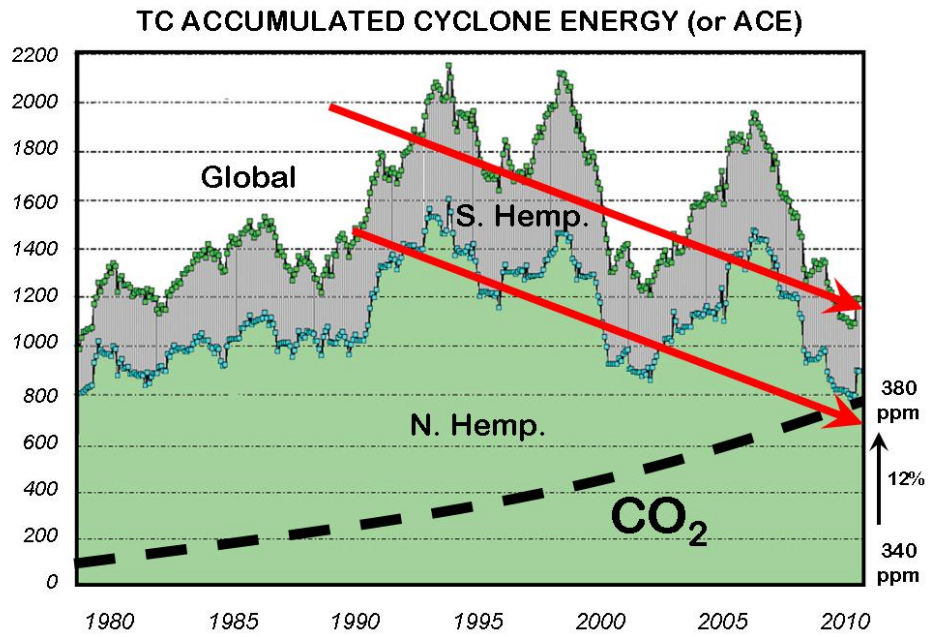
**A RECENT TC CLIMATE MODELING PAPER.** There has recently been a climate modeling paper projecting future TC activity by T. Knutson and 9 other authors (2010) saying that during the remainder of the 21<sup>st</sup> century that we should expect to experience fewer global tropical cyclones. However, the TCs which do form will tend to be stronger than the ones in the past due primarily to increases of CO<sub>2</sub>. This is an example of pure (and unreliable) climate model speculation. There is absolutely no objective basis for this near century-long forecast of TC

activity. Any sensible observer knowing how faulty the GCM global warming predictions of the IPCC-AR4 are should not put any confidence at all in such a down-scaled version of the GCMs from which this near century long TC forecast has been derived.

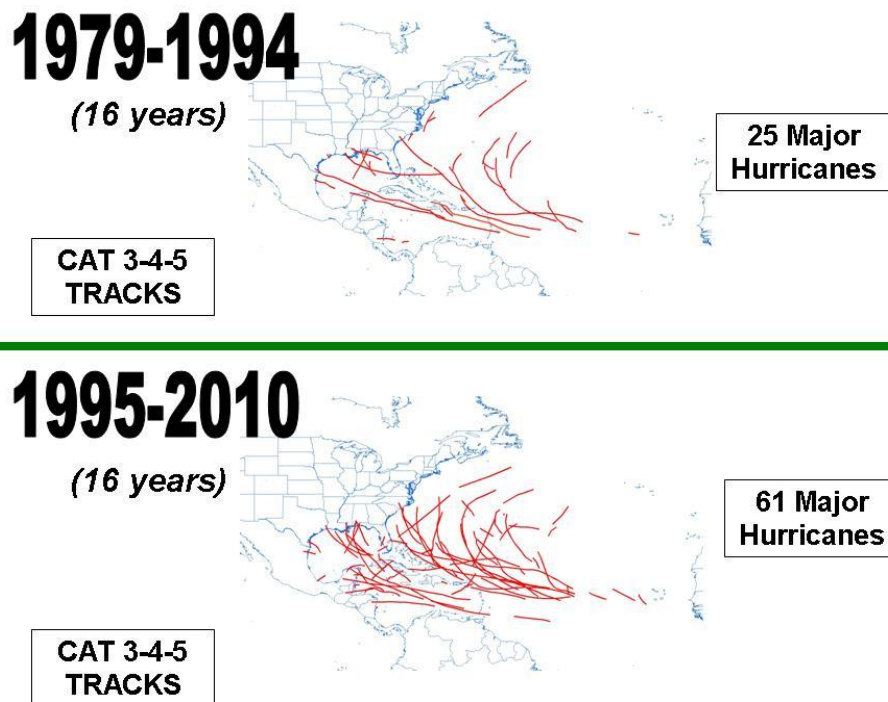
### **13. IPCC-AR4's OMISSION OF THE CAUSES OF THE LARGE MULTI-DECADAL VARIATIONS IN ATLANTIC BASIN MAJOR HURRICANES AND US LANDFALL**

Despite the downward trend of global net TC activity (as illustrated in Figure 13.1) there has been a large increase in Atlantic basin major hurricane activity since 1995 in comparison to the prior 16-year period of 1979-1994 (Figure 13.2) and the prior quarter-century period of 1970-1994. It has been tempting for many who do not have a background in Atlantic hurricane history to jump on this recent 16-year increase in major Atlantic hurricane activity as evidence of an AGW influence on hurricanes. It should be noted, however, that the last 16-year active major hurricane period of 1995-2010 has not been more active than the earlier 16-year period of 1949-1964 when the Atlantic THC conditions were similar to what has been observed over the last 16 years (Table 13.1). These very active earlier period conditions occurred even though atmospheric CO<sub>2</sub> amounts and global SSTs were lower than during the recent 16-year period. The IPCC-AR4 failed to note and discuss this very strong Atlantic multi-decadal TC signal, the knowledge of which would likely have tempered the IPCC from saying that TC activity was undergoing such large increases in recent years. These recent TC increases were occurring only in the Atlantic, while in the other global TC basins, TC activity was on a downward trend.

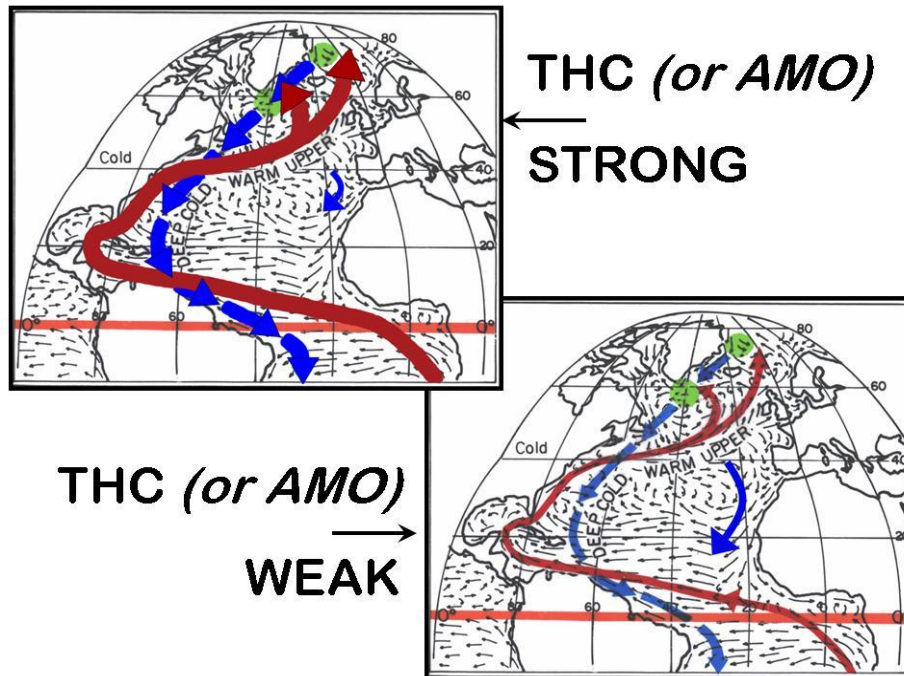
**CAUSES OF ATLANTIC UPSWING IN MAJOR HURRICANE ACTIVITY SINCE 1995.** The Atlantic Ocean has a strong multi-decadal signal in its hurricane activity which I am very confident is a result of multi-decadal variations in the THC (Figure 13.3). This circulation is driven by multi-decadal variations in North Atlantic salinity. The global ocean's response to this THC is often referred to as the Atlantic Multi-decadal Oscillation (AMO). I use the THC and AMO interchangeably throughout this discussion. The strength of the THC can never be directly measured, but it can be diagnosed, as we have done, from a combination of the magnitude of the SST anomaly (SSTA) in the North Atlantic (Figures 13.4 and 13.5), the North Atlantic salinity anomaly (Figure 13.6 and 13.8), the sea level pressure anomaly (SLPA – Figure 13.7) in the Atlantic between the latitudes of the equator and 50°N and the North Atlantic surface zonal wind anomaly between 40-50°N; 10-70°W. Figure 13.7 shows the combination of parameters which combine to give this proxy of the strength of the THC (or AMO).



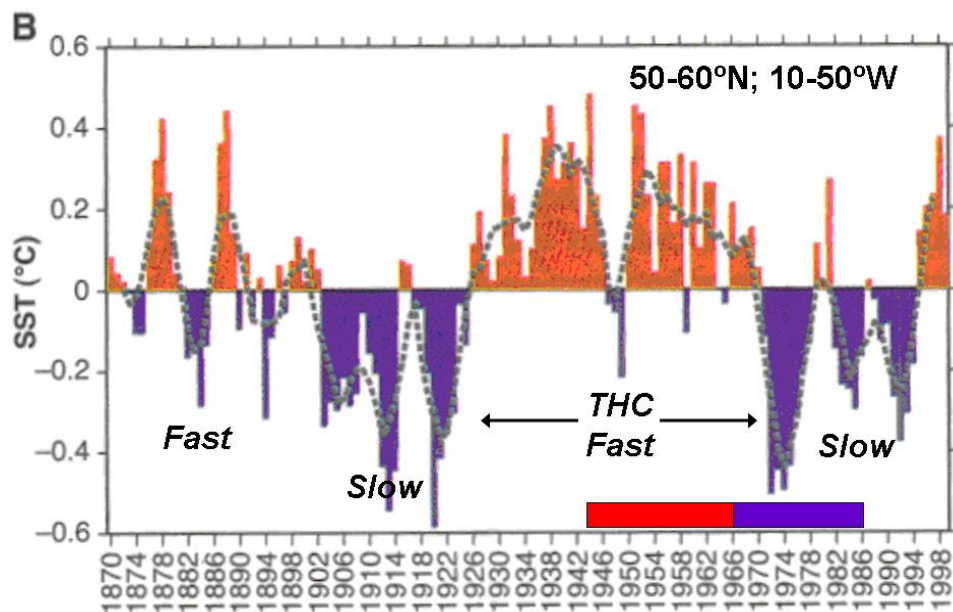
**Figure 13.1** – Global ACE ( $\Sigma V_{max}^2$  for a year) from 1979-2010. Red lines indicate that global and N. Hemisphere ACE has been trending downward over the last 20 years despite increases in  $CO_2$  (Adapted from Ryan Maue).



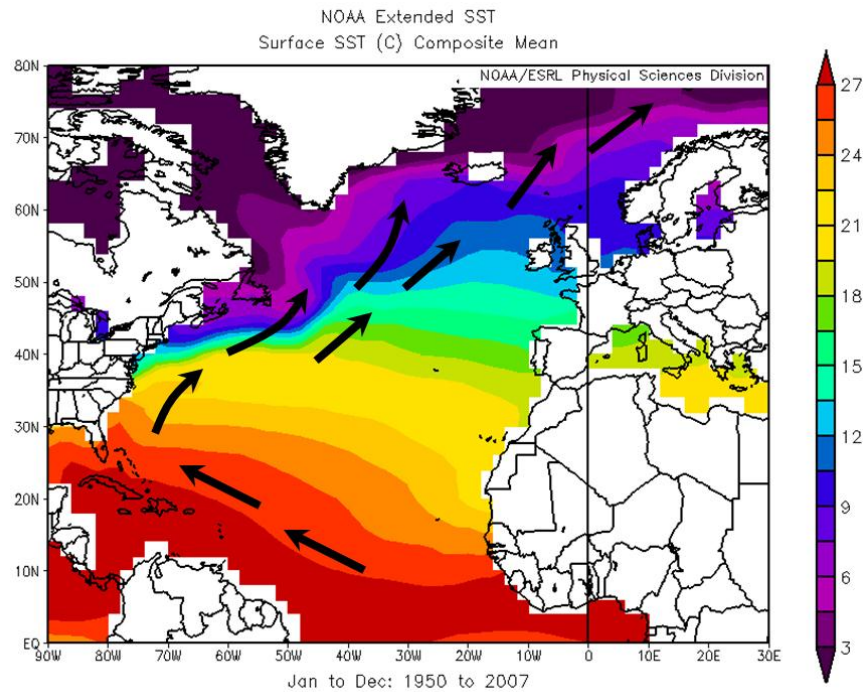
**Figure 13.2** – The tracks of major (Category 3-4-5) hurricanes during the 16-year period of 1979-1994 when the THC was weak versus the 16-year period of 1995-2010 when the THC was strong. Note that there were approximately 2.5 times as many major hurricanes when the THC was strong as when it was weak.



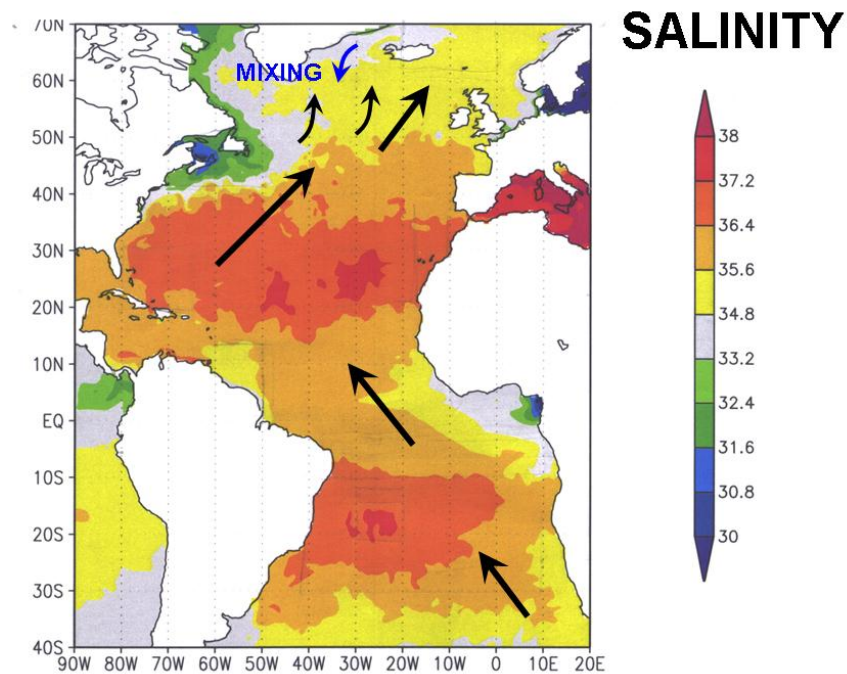
**Figure 13.3** – Illustration of strong (top) and weak (bottom) phases of the THC or AMO.



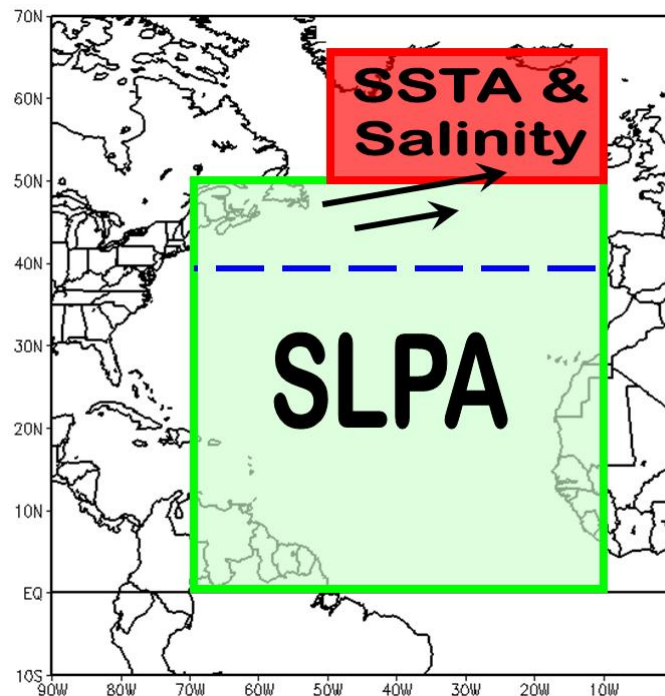
**Figure 13.4** – Long-period portrayal (1878-2006) of North Atlantic SST anomaly. The red (warm) periods are when the THC is stronger than average and the blue periods are when the THC is weaker than average. Major hurricanes are much more frequent during the red periods.



**Figure 13.5** – Climatology of North Atlantic SST with arrows showing the upper ocean Gulf Stream and North Atlantic Current circulation and how it advects (black arrows) warm water poleward.



**Figure 13.6** – Atlantic surface salinity content and how the Gulf Stream and North Atlantic Current (black arrows) advects higher salinity water into the North Atlantic.



**Figure 13.7** – Proxy parameters used to diagnose the strength of the Atlantic THC. We judge its strength to be closely approximated by the formula  $(SSTA + SA) - (SLPA + UA)$  in the areas shown. SSTA stands for North Atlantic Sea Surface Temperature Anomaly, SA for North Atlantic Salinity Anomaly, SLPA stands for Sea Level Pressure Anomaly and UA is surface zonal wind anomaly.

Table 13.1 shows how large Atlantic basin hurricane variations are between strong and weak THC periods. Note especially how large the ratio is (3.7) for major (Cat 3-4-5) hurricane days (MHD) during strong vs. weak THC periods.

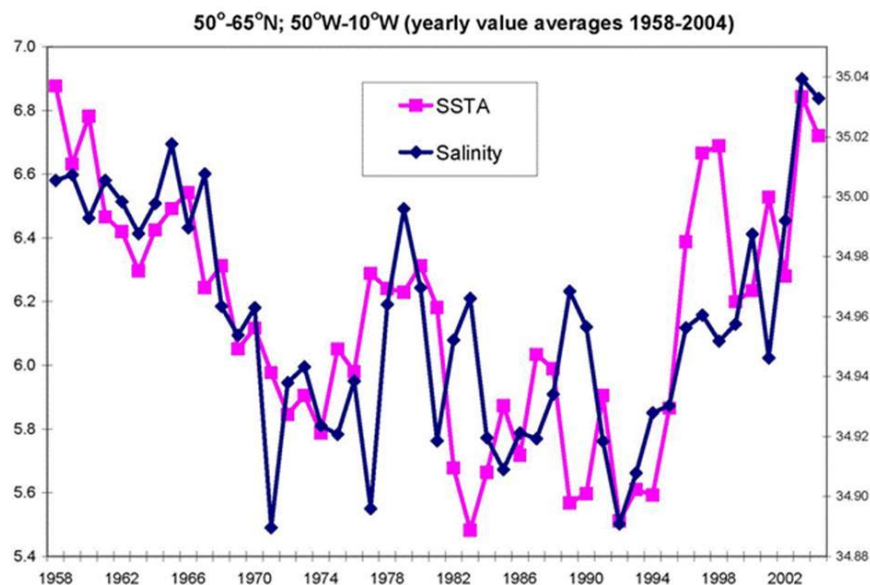
Figure 13.8 illustrates the close association between North Atlantic SST and North Atlantic salinity. This figure can only be interpreted as showing that North Atlantic SST and salinity are mutually responding to the strength of the Atlantic's THC. A strong THC advects poleward both higher temperature and higher salinity water. A weaker THC advects significantly less. Changes of SST in the range just above freezing ( $0-7^{\circ}\text{C}$ ) have much less influence on ocean density than do salinity variations in this cold range. It is possible for warmer ocean water ( $4-7^{\circ}\text{C}$ ) to be more dense than colder ocean water ( $0-3^{\circ}\text{C}$ ) if the warmer ocean water has a higher salinity content.

Normalized U.S. hurricane damage studies by Pielke and Landsea (1998) show that landfalling major hurricanes account on average for about 80-85 percent of all hurricane-related destruction even though these major hurricanes make up only 20-25 percent of Atlantic named storms. Variations in US multi-decadal hurricane damage cannot be understood without knowing the multi-decadal variations in the strength of the THC.

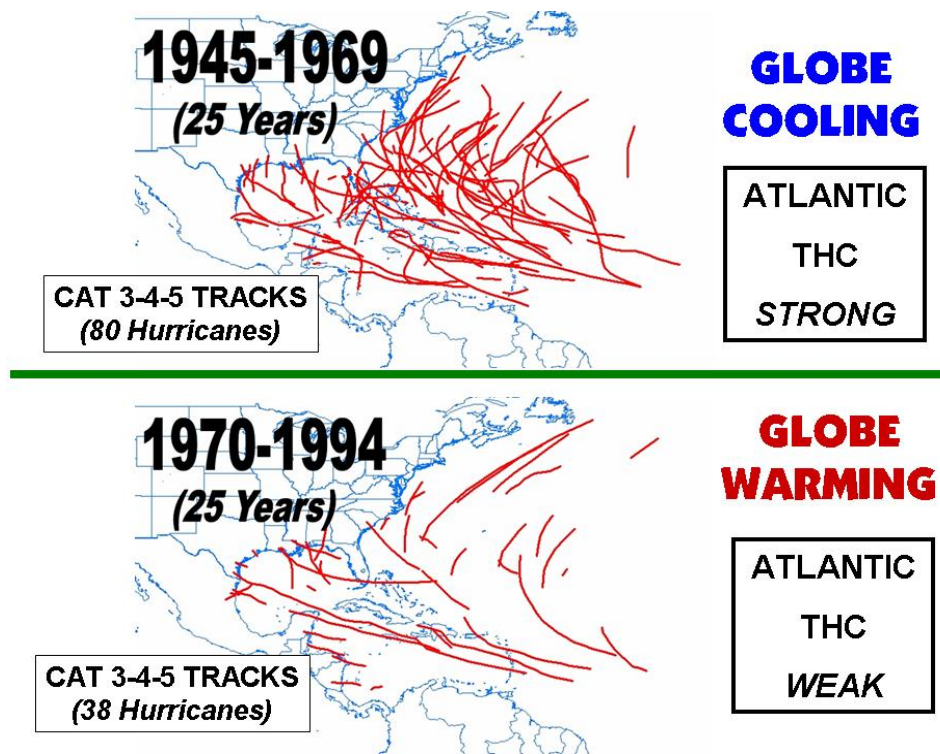
**Table 13.1** – Comparison of Atlantic basin mean annual hurricane activity in two 16-year periods when the Atlantic Ocean THC (or AMO) was strong versus an intermediate period (1970-1994) when the THC was weak.

	THC	SST (10-15°N; 70-40°W)	Avg. CO <sub>2</sub> ppm	NS	NSD	H	HD	MH	MHD	ACE	NTC
<b>1949-1964 (16 years)</b>	Strong	27.93	319	10.1	54.1	6.5	29.9	3.8	9.5	121	133
<b>1970-1994 (25 years)</b>	Weak	27.60	345	9.3	41.9	5.0	16.0	1.5	2.5	68	75
<b>1995-2010 (16 years)</b>	Strong	28.02	373	14.6	74.1	7.8	32.0	3.8	9.4	140	153
<b>Annual Ratio Strong/Weak THC</b>		$\Delta 0.35^{\circ}\text{C}$	$\sim 0$	1.3	1.5	1.4	1.9	<u>2.5</u>	<u>3.7</u>	1.9	1.9

In the quarter-century period from 1945-1969 when the globe was undergoing a weak surface cooling trend, the Atlantic basin experienced 80 major (Cat 3-4-5) hurricanes and 201 major hurricane days. By contrast, in a similar 25-year period from 1970-1994 when the globe was undergoing a general warming trend, and CO<sub>2</sub> amounts were higher, there were only 38 Atlantic major hurricanes (48% as many) and 63 major hurricane days (31% as many) (Figure 13.9). Atlantic hurricane activity certainly did not match the trend in global mean SST change or the trend in CO<sub>2</sub> change over these two 25-year periods.



**Figure 13.8** – Illustration of the strong association of yearly average North Atlantic SSTA and North Atlantic salinity content between 1958 and 2004.



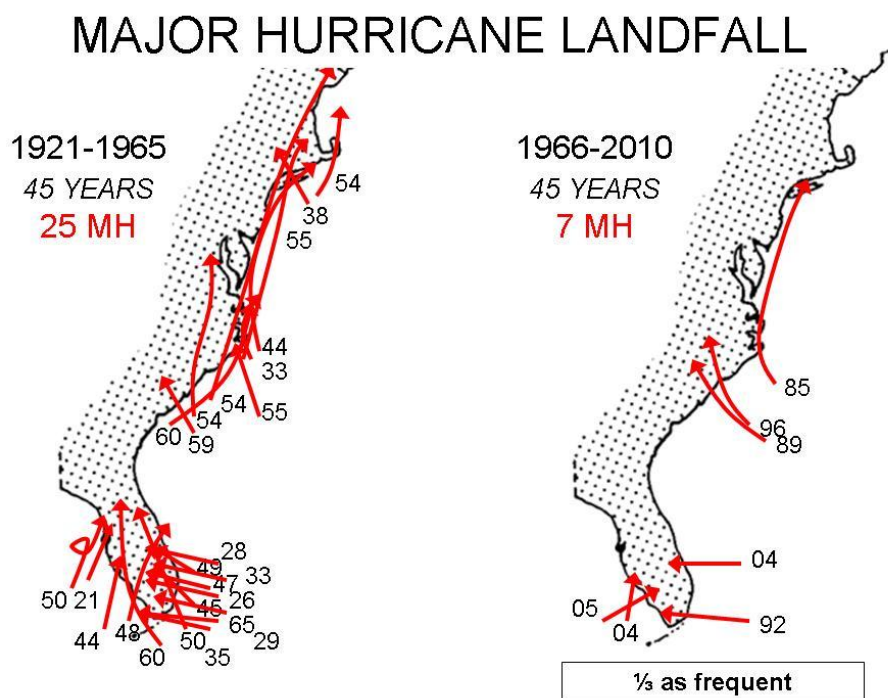
**Figure 13.9** – Tracks of major (Category 3-4-5) hurricanes during the 25-year period of 1945-1969 when the globe was undergoing a weak cooling versus the 25-year period of 1970-1994 when the globe was undergoing a modest warming.  $\text{CO}_2$  amounts in the later period were approximately 18 percent higher than in the earlier period. MHD activity was only about one-third as frequent during the latter period despite warmer global temperatures and higher amounts of  $\text{CO}_2$ .

The most reliable long-period hurricane records we have are the measurements of US landfalling TCs since 1900 (Table 13.2). Although global mean ocean and Atlantic SSTs have increased by about  $0.4^\circ\text{C}$  between these two 55-year periods (1901-1955 compared with 1956-2010), the frequency of US tropical storm and hurricane landfall numbers actually shows a downward trend. This downward trend is particularly noticeable for the US East Coast and Florida Peninsula where the difference in landfall of major (Category 3-4-5) hurricanes between the 45-year period of 1921-1965 (24 landfall events) and the last 45-year period of 1966-2010 (7 landfall events) was especially large (Figure 13.10). For the entire United States coastline, 40 major hurricanes made landfall during the earlier 45-year period (1921-1965) compared with only 22 major hurricanes for the latter 45-year period (1966-2010). This occurred despite the fact that  $\text{CO}_2$  averaged approximately 365 ppm during the latter period compared with 310 ppm during the earlier period. Figure 13.11 shows a downward trend of US major hurricane landfalls with rising levels of  $\text{CO}_2$ .

**Table 13.2** – U.S. landfalling TCs by intensity during two 55-year periods.

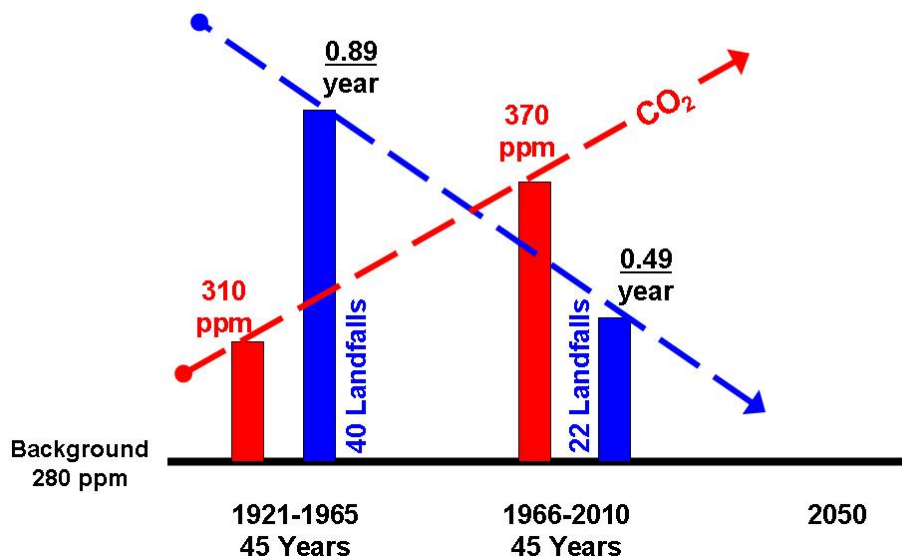
YEARS	NAMED STORMS	HURRICANES	MAJOR HURRICANES (CAT 3-4-5)	GLOBAL TEMPERATURE INCREASE
<b>1901-1955 (55 years)</b>	210	115	44	+0.4 °C
<b>1956-2010 (55 years)</b>	180	87	34	

We should not read too much into the two very active hurricane seasons of 2004 and 2005. The activity of these years was unusual but well within natural bounds of hurricane variation. What made the 2004-2005 seasons so destructive was not the high frequency of major hurricanes but the high percentage of hurricanes that were steered over the US coastline. The US hurricane landfall events of these two years were primarily a result of the US-directed surrounding TC tropospheric steering currents which advected these many TCs over land.



**Figure 13.10** – Contrast of tracks of East Coast and Florida Peninsula major landfalling hurricanes during the 45-year period of 1921-1965 versus the most recent 45-year period of 1966-2010.

# US Landfalling Major Hurricanes



**Figure 13.11** – Illustration of how US landfalling major hurricane numbers have been trending downward while CO<sub>2</sub> values are increasing.

Although 2005 had a record number of TCs (28 named storms), this should not be taken as an indication of something beyond natural variability. The historical records indicate that there have likely been a few other years with comparable hurricane activity to 2005. For instance, 1933 had 21 recorded named storms in a year when there was no satellite or aircraft data. Records of 1933 show all 21 named storms had tracks west of 60°W where surface observations were more plentiful. If we eliminate all the named storms of 2005 whose tracks were entirely east of 60°W and therefore may have been missed given the technology available in 1933, we reduce the 2005 named storm total by seven (to 21) – the same number as was observed to occur in 1933 (Landsea 2007).

Utilizing the National Hurricanes Center's best track database of hurricane records back to 1851, we find that six previous seasons had more hurricane days than the 2005 season. These years were 1878, 1893, 1926, 1933, 1950 and 1995. Also, five prior seasons (1893, 1926, 1950, 1961 and 2004) had more major hurricane days than the 2005 season. Although the 2005 hurricane season was certainly one of the most active on record, it was not as much of an outlier as many have indicated.

I believe that the Atlantic basin remains in an active hurricane cycle which results from the strong THC that has been present since 1995. This active cycle is expected to continue for another decade or two at which time we should enter a quieter Atlantic major hurricane period more typical of what the Atlantic experienced during the quarter-century periods of 1970-1994 and 1901-1925. Atlantic hurricanes (particularly major hurricanes) go through strong multi-decadal cycles. Such multi-decadal THC-driven cycles have been observationally traced back to the mid-19<sup>th</sup> century. Changes in the THC have also been inferred from Greenland paleo ice-

core temperature measurements going back thousand of years. These changes are natural and have nothing to do with human activity.

**RECENT DECADES LUCK OF DECREASING US MAJOR HURRICANE LANDFALL.** Since the start of the THC-induced active period in 1995 the US has been very lucky, except for the very destructive seasons of 2004 and 2005. In the last 16 seasons (excluding 2004-05) the US coast has only been struck by three other landfalling major hurricanes (Opal, 1995; Fran, 1996; Bret, 1999). In the last 39 of 41 years of 1970-2010 (excluding 2004-2005) Florida and the US East Coast has been struck by only 5 of 86 (6 percent) Atlantic basin major hurricanes. By contrast, in the 31 year period of 1941-1969 and 2004-2005 Florida and the US east coast experienced 24 of 82 (28 percent) Atlantic basin major landfall events. This is a per year major landfall difference of over 6 to 1. How many Florida Peninsula and US East Coast residents know how lucky they have been over the last 40 years (except for 2004-2005)? Excluding the two seasons of 2004-2005, the US has experienced no major landfall events since 1999 or in the last 9 of 11 years. This luck should not be expected to continue.

#### **14. THE OCEAN AS A POWERFUL MODULATOR OF GLOBAL CLIMATE AND ATLANTIC MAJOR HURRICANE ACTIVITY**

One of the most unique features of the earth in comparison with other planets is that its surface is covered by almost 70 percent water (with a global average depth of 3.8 km). Having deep oceans covering so much of the globe means that the earth's surface can absorb, store and give out vast quantities of energy which are not directly related to the current in-and-out radiation of the earth and only weakly related to the ocean's SST. The earth's surface and atmospheric temperatures of each hemisphere would warm up many times more in summer and cool down many times more in winter if the globe's percent of ocean surface were substantially less. Global temperature is not regulated by radiation alone. Ocean to air energy flux variations also plays a large role.

The earth's surface is continually absorbing substantially more solar energy than it re-radiates as long-wave energy back to the atmosphere. A high percent (~ 50 percent) of the globe's surface solar energy absorption is expended to evaporative water. The other half of the surface solar radiation energy absorption that is not expended in evaporative water is given to surface IR and sensible energy flux to the atmosphere above or is stored as excess or deficit ocean energy. The middle and high latitude oceans store great quantities of energy in spring and summer and give off very large quantities of this stored energy to the atmosphere in the fall and winter.

**CIRCULATION CHANGES RELATED TO THE STRONG VS. WEAK MODES OF THE THC.** There are distinct multi-decadal parameter differences in the global atmospheric and global ocean's general circulation during periods when the Atlantic Thermohaline Circulation (THC) is strong versus periods when it is weak. Table 14.1 illustrates these differences. Figure 14.1 gives a graphical illustration of these features. We hypothesize that these multi-decadal global circulation changes are primarily a result of naturally occurring multi-decadal changes in the Atlantic Thermohaline Circulation (THC) or the Meridional Overturning Circulation (or MOC) which is largely driven on long time scale ocean salinity variations. One should expect little or no influence to THC changes from variations in solar radiation or from increases in atmospheric CO<sub>2</sub> content.

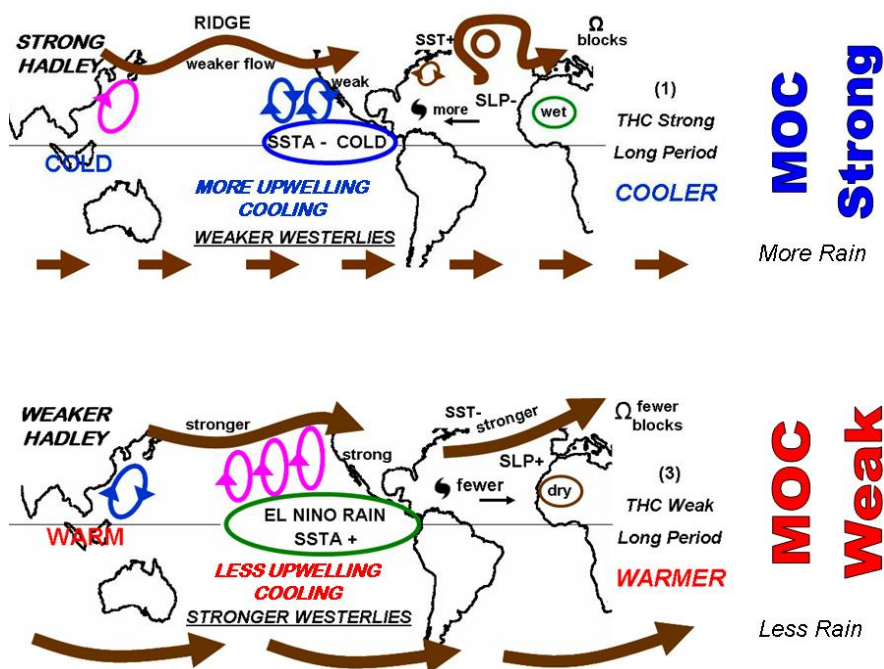
Knowing these typical multi-decadal parameter variations of Figure 14.1, it is thus possible to make multi-decadal forecasts of parameters which have been shown to be associated with the THC strong or weak modes. For instance, the author has used historical information of multi-decadal fluctuations in THC strength to issue multi-decadal forecasts of future Atlantic basin hurricane activity and future multi-decadal global temperature change.

The Atlantic THC switched from its long multi-decadal period of being weak (1970-1994) to becoming strong in 1995. It has continued in this strong mode since (1995-2011), and if the future is like the past this strong THC should be expected to continue for another 10-15 years or so. It is then likely that the North Atlantic will have exhausted its current higher than average levels of salinity content and the THC will consequently weaken to below-average strength. When this happens the current higher levels of hurricane conditions which have been experienced since 1995 will switch over to conditions more in line with the lower-levels of activity which was experienced during the quarter century period between 1970-1994, or the period between 1900-1925.

Figure 14.2 is a quote of a multi-decadal forecast which I issued in 1996 about the expected large future increase in hurricane activity that I expected to occur at that time. See Figure 13.2 to observe how well the increased hurricane portion of this forecast verified. Also, the global cooling part of this forecast appears to have merit in that during the last decade, mean global temperature appears to be entering a weak cooling phase. I anticipate continued weak global cooling over the next decade or two due to the expected continuance of the current strong THC pattern.

**Table 14.1** – Contrast of 6 basic global parameter circulation features (center column) when the Atlantic THC (or MOC) is strong (left column) in comparison with when it is weak (right column).

MULTI-DECADAL PERIODS WHEN THE (THC) IS <b>STRONG</b>	GLOBAL PARAMETER	MULTI-DECADAL PERIODS WHEN THE (THC) IS <b>WEAK</b>
More rain	Global Rainfall	Less rain
Cooling	Mean Global Temperature Trend	Warming
Less Frequent & Weaker	El Nino Activity	More Frequent & Stronger
Weaker	Atlantic Mid-Latitude Zonal Wind Strength	Stronger
Weaker	Strength of N. Atlantic Subtropical Oceanic Gyre Circulation and Atmospheric High Pressure	Stronger
Higher	Atlantic Hurricane Activity (particularly major hurricane activity)	Lower



**Figure 14.1** – Portrayal of typical global circulation differences between a strong and a weak THC or Meridional Overturning Circulation (MOC). The globe typically undergoes cooling and less rainfall during strong vs. weak phases of the THC or MOC.

**21st NOAA Climate Workshop, Huntsville, AL (1996)**

**FORECAST OF GLOBAL CIRCULATION  
CHARACTERISTICS IN THE NEXT 25-30 YEARS**

William M. Gray  
(written in 1996)

We expect that these changing THC (or MOC) patterns will lead to enhanced intense (or major) hurricane activity in coming years and to a small global surface temperature cooling. It is likely that the mean global surface temperature change in the next 20-30 years will be more driven by nature than by anthropogenic influences and be one of weak cooling, not warming.

***Figure 14.2** – Forecast the author issued in 1996 concerning an anticipated increase in Atlantic basin hurricane activity after the onset of the strong THC in 1995 – and the expected decrease in global temperature in coming decades. This forecast was simply based on the observed change in the strength of the THC (or AMO) and the expected multi-decadal parameter changes which are associated with such THC pattern changes (Table 14.1). No consideration was given to rising levels of CO<sub>2</sub>.*

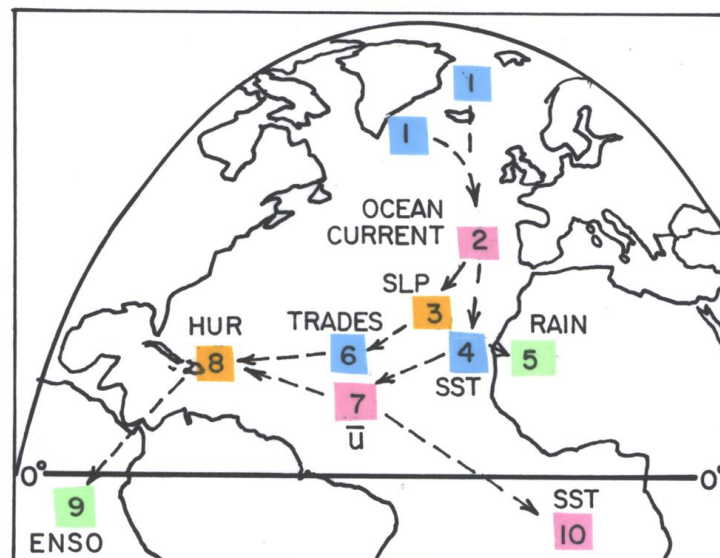
**THEORY OF THC (OR AMO) INFLUENCE ON ATLANTIC HURRICANE VARIABILITY.** The seasonal hurricane variability in the Atlantic cannot be explained by changes in CO<sub>2</sub>-induced radiation. The SST changes which the Atlantic Ocean experiences are due primarily to the variations in the strength of the multi-decadal southwest to northeast North Atlantic upper poleward branch of the THC in the high latitude Atlantic. The THC is strong when there is an above-average poleward advection of warm tropical waters to the high latitudes of the Atlantic. This poleward-moving water can then sink to deep levels if it has high enough salinity content. This sinking process has been termed North Atlantic Deep Water Formation (NADWF). The submerged deep water then moves southward at deep levels in the Atlantic into the Southern Hemisphere. The amount of North Atlantic water that sinks is roughly proportional to the waters' density which at high latitudes, where water temperatures are low, is primarily dependent on salinity content. The strong association between North Atlantic SSTA and North Atlantic salinity has been shown in Figure 13.8. High salinity implies higher rates of NADWF.

Through a progression of associations the strength of the NADWF is hypothesized to bring about alterations of the tropospheric vertical wind shear, trade wind strength, SSTs, middle-level water vapor, and other conditions in the Atlantic Main Development Region (MDR – 10-20°N; 20-70°W). The favorable changes of SST in the MDR are a consequence of a combination of the ocean's THC influences on a variety of parameters in the Atlantic's MDR (Figure 14.3). A stronger than average THC causes more ocean sinking in area 1. This in turn reduces the strength of the Atlantic gyre. There is then a change in all of the other conditions shown in Figure 14.3 to bring about more favorable parameters in the MDR for TC formation and

intensification. This figure illustrates how the changing rate of southward advection of colder water in the east Atlantic (2) brings about alterations of SLP (3), SST (4), and rainfall (5). These changes in turn lead to changes in trade wind strength (6) and 200 mb zonal wind (7). Changes in hurricane activity follow. These changing conditions bring about weaker trade winds and reduced evaporation which typically acts to increase SST. It is also found that in periods with a strong THC, El Niño frequency and intensity is typically reduced (9) and Atlantic hurricane activity, particularly major hurricane activity, is enhanced.

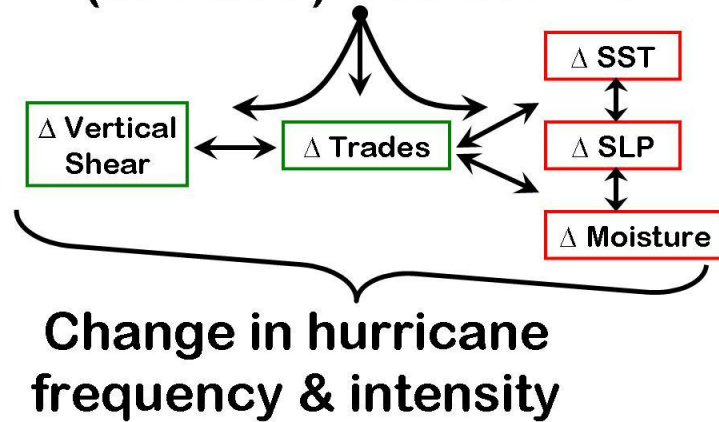
The influence of the warmer Atlantic SST is not primarily to enhance lapse rates and Cb convection in the MDR but to act as a net overall positive or negative influence on a combination of parameters that must all change in a positive way to enhance MDR TC activity. These features typically all go together as a package to either enhance or to inhibit TC formation and/or TC intensity change (Figure 14.4). The simple argument of rising or lowering levels of SST alone, without other important parameter changes is not typical of what we observe with TC activity variation in this region.

Higher rates of NADWF require stronger northward moving west Atlantic replacement water which is typically warmer, and if the stronger poleward flow is to continue, the replacement water must be of higher salinity content and consequently of higher density when such water cools toward freezing. Salinity dominates over water temperature when water temperatures are in the range of 0-7°C above freezing. Figure 14.5 shows how unique the Atlantic Ocean's salinity contents are at both the surface and at 500 m depth. See the papers by Gray *et al.* (1997); Goldenberg *et al.* (2001), Grossmann and Klotzbach (2009) and Gray and Klotzbach (2011) for more discussion of this topic.

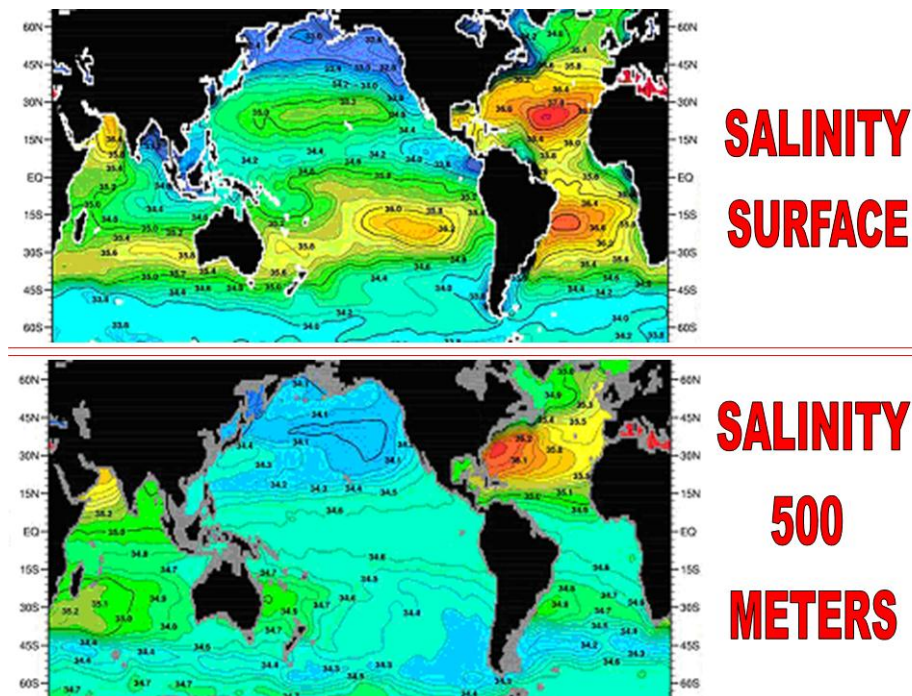


**Figure 14.3** – Idealized analysis of how changes in North Atlantic SST and salinity (area 1) lead to progressive wind, pressure, SST, vertical shear or rain changes as portrayed in these 9 areas. It is this complete package of Atlantic/eastern Pacific meteorological parameter changes on a multi-decadal time scale which cause large and unique changes in Atlantic major hurricanes on this time scale.

# ATLANTIC OCEAN THC (or AMO) CHANGES



**Figure 14.4** – Idealized portrayal of how changes in the Atlantic THC bring about various parameter changes in the Atlantic’s MDR between 10-20°N; 20-70°W. Vertical shear, trade-wind strength SLP and SST are the key parameters which respond to the THC changes. Favorable SLPA and mid-level moisture changes occur in association with the shear, trade wind, and SST changes. It is the THC’s ability to affect a favorable alteration of a combination of these parameters within the MDR which leads to such a strong association between the strength of the THC and major hurricane frequency.



**Figure 14.5** – Global surface and 500 meter depth salinity which illustrates how unique the Atlantic is in comparison to the other ocean basins. Higher salinity in the Atlantic is primarily due to its higher evaporation over precipitation.

## 15. DISCUSSION

The author has spent his whole professional life (since 1953) in forecasting, researching and teaching meteorology and climate. I have thought long and hard on the question of the influence of rising CO<sub>2</sub> levels on the earth-climate system. My over 40 years of graduate-level class preparations have forced me to remain alert and continue to exercise my curiosity as to how the global atmosphere and oceans function. I have had to continuously revise my class lectures as the years went by, and as I grew in my understanding as to how the weather and climate system functions.

My long career led me very early to be in disagreement with the AGW scenarios which have been so strongly advanced over the last 20 years by thousands of scientists, government leaders, environmentalists, and many others. I have observed that the AGW scenarios have been most vigorously advanced, in general, by individuals with inadequate understanding of how the global weather and climate system behaves. Those believing the most in global warming have been far too strongly conditioned to put reliability in the GCMs simulations rather than upon real observations and knowledge-driven physical reasoning. It is the less experienced who are prone to put the most reliability in the climate models.

It is the nature of and the understanding of the functioning of the complex hydrologic cycle and the globe's deep ocean circulation which the AGW advocates do not have observational experience with. These omissions have led them to their unrealistic warming exaggerations. Another major problem has been the belief among so many of the AGW advocates that it is possible to construct GCMs which will be able to skillfully predict future global climate change. This is not possible given the turbulent and grossly chaotic nature of the global atmosphere and ocean circulations. Global predictions have shown forecast skill only out to 10-15 days, but not beyond that. If skillful global climate forecasting were indeed possible, we would expect the modelers to issue formal 1, 3 and 5 year future climate forecasts that could be verified. They will not do this because they know they do not have short range forecast skill and would rapidly lose credibility. Why should we then believe them at 50 to 100 years?

The four IPCC reports (that have been issued every 4-5 years since the early 1990s) were supposed to have reflected the latest and best available judgments about future climate and the physical processes which may cause such changes. These reports, however, were conceived, organized, and implemented by scientists and government officials who already had a built-in desire to show an exaggerated degree of future global temperature increase from rising levels of CO<sub>2</sub>. If increased TC activity could also be tacked on to the CO<sub>2</sub> global warming scenario, so much the better.

Although much of the detailed data analyses within the IPCC reports were timely and enlightening, the summary conclusions were heavily edited to agree with the many GCM results and what the IPCC organizers wanted to read. No matter what the internal data analysis of these IPCC reports might indicate, the Summary for Policy Makers (SPM) could always be counted on to indicate that the doubling of the levels of CO<sub>2</sub> would cause large increases in global temperature (2-5°C or 4-9°F) and cause more intense TCs. Many of the globe's most

knowledgeable meteorologists knew or suspected that scientific objectivity had been compromised (or abandoned) in each of the four IPCC report summaries. But the mainstream media was and continues to be reluctant to publish scientific criticism of the IPCC reports which carried such international high-level government backing.

The discussion of TCs by the IPCC-AR4 report was written by individuals knowing very little about TCs. Most statements about TCs were inaccurate. The major IPCC-AR4 TC conclusions were obtained from the discredited published papers of prominent scientists such as Emanuel, Webster, Holland, Curry, Trenberth, Mann, Santer, and others. There is no question that the IPCC-AR4 report was directed (from the start) towards saying that TCs were getting stronger and that these increases were due to increases in CO<sub>2</sub>. No matter what the observations showed, the preconceived summary view that TCs were getting more intense due to rising CO<sub>2</sub> levels was going to go forward.

Despite the global warming of the sea surface that has taken place in the last century and between the mid 1970s to the late 1990s, the global numbers of TCs and hurricanes and their intensity have not shown any upward trends except for multi-decadal TC variations in the Atlantic. There is no way that such large changes in the Atlantic can be explained from miniscule CO<sub>2</sub> IR blockage increases of about 0.5 Wm<sup>-2</sup> that have taken place during the last 40 years.

It is possible that rising future levels of CO<sub>2</sub> may, in ways yet unknown, be able to cause a miniscule influence on global TC activity. But any such potential influence, as indicated by the tropical energy budget (section 9), will likely be much too small to ever be reliably isolated. We also do not know whether this CO<sub>2</sub> influence would act to enhance or suppress TC intensity or frequency.

The AGW advocates are particularly deficient in their understanding in how the globe's hydrologic cycle functions. This includes the false belief that the globe's upper-tropospheric relative humidity (RH) will remain constant if upper tropospheric temperatures increase. This faulty RH assumption produces a strong positive correlation between rainfall and upper troposphere temperature-moisture that is not found in the observations. In addition, GCMs have yet to properly take into account the large enhancement of albedo from the tops of the deep convective clouds. Albedo enhancement is larger than IR suppression in these rain cases. Enhanced cloud albedo further reduces warming. There also remains the fundamental basic question of salinity-driven changes in the globe's deep ocean.

It does not follow that changing amounts of TC activity are related very much to changes of SST except in the Atlantic basin where it is not the SST increases by themselves which are the primary drivers of the Atlantic's hurricane activity variations, but the tropical cyclone-enhancing changes brought about by the combination of the tropical Atlantic's trade wind strength, wind shear, surface pressure, mid-level moisture, etc. which are closely associated with the Atlantic's SST changes. It is the combined package which is essential, not the single parameter of SST. All these changes are a product of the strength of the THC.

Sea surface temperatures in the non-Atlantic TC basins vary little from season to season. By contrast, TC activity (or ACE) can, in percentage terms, vary quite substantially from season to season. How can variations in ACE have so little association with SST if SSTs are the fundamental ingredient of these storms?

Historical evidence from a variety of sources indicates that there were likely just as intense hurricanes during the Little Ice Age (when tropical SSTs were likely somewhat cooler) than there have been in recent years.

There are many individuals with extensive experience and much knowledge of TCs that have much to contribute on the question of CO<sub>2</sub>-TC activity that have been ignored by the IPCC because they do not agree with the CO<sub>2</sub>-induced warming arguments.

The exaggerated claims by the many papers listed in Table 3.1 which served as a basis for the erroneous IPCC-AR4 statements on TCs has likely led to millions of readers being misinformed about the influence of rising levels of CO<sub>2</sub> on TCs. Most readers of the IPCC-AR4 report would be inclined to put confidence in a report which shared a Nobel Peace Prize.

The authors of the Table 3.1 papers appear not to have comprehended the implications of their papers upon a much larger and more serious arena than the typical TC papers that are published within the restricted peer group of TC researchers. Most TC papers don't go much beyond the TC peer group and can do little harm. As well established senior scientists, this cadre of individuals of Table 3.1 had a professional responsibility (beyond their own personal interests) not to falsely alarm the public at such an unusual period following the destructive U.S. hurricane seasons of 2004-2005.

The implied false idea of CO<sub>2</sub> bringing about global warming and enhancing hurricane intensity and frequency are now entrenched in the minds of millions of people. We can expect these ideas to surface again and again in the media in the coming years when the US and other countries receive major hurricane-spawned destruction.

Most of the primary hurricane-AGW alarmists have yet to backtrack on their misleading statements of the 2005-2008 periods. As the lack of reality of their AGW claims are now beginning to be realized, some of the alarmists may try to quietly ignore and distance themselves from their earlier papers and media pronouncements. They may claim that new data and research has caused them to change their mind. They should not so easily be let off the hook.

Senior meteorologists in prominent positions as those 16 individuals listed in Table 8.2 should have developed, over the years, a better intuitive feeling about how the atmosphere-ocean functions. They should have been more surprised and far more critical of their data which, if correct, had profound meaning for global climate change and for humanity. As well-respected scientists they should have been more cautious and should not have so easily surrendered their objectivity and their responsibility as scientists. Their papers, statements, and behind the scene activities gained them much publicity and were likely helpful with their federal research support and program advancements. But their gross errors and exaggerations (and the media's

compliance to their findings and statements) have brought unnecessary worry and anxiety to many millions of people living along the globe's vulnerable TC coastlines. Their statements also helped build the erroneous perception of AGW.

We don't know how much the Atlantic basin and global TC communities have suffered from these scientists' erroneous TC pronouncements. How many people living along or within the global storm basins decided to move to less vulnerable areas after the 2005 season? How many decided not to move or to visit such vulnerable locations? How many have seen their real estate values altered and/or their home or business insurance rates increased by these erroneous TC pronouncements and the resulting media exaggerations? Scientists should not feel they have the freedom to falsely scream 'storm-surge' or 'tsunami' along crowded beaches. Federal grant support should carry with it a higher degree of required social responsibility than these TC warmers have exhibited.

**PARTING SHOT.** It is hoped that this long discussion of sections 9-14 (Part II- Science Discussion) – for those of you who had the fortitude to read it through – has led you to a better understanding of the complex physics of tropical cloud clusters and of TCs and their unlikely prospects of being significantly altered by CO<sub>2</sub> increases. Science should not be trampled on by ideologists driven by self-interest and a contempt for public welfare. The gall of such a crowd to play the public for suckers (as they have done) and to pocket a Nobel Prize along the way.

## **16. AUTHOR'S CLIMATE VIEWS AND RECOMMENDATIONS**

Advancements in Numerical Weather Prediction out to 10-15 days have been a great success story. I have watched and admired its steady progress over the last 55 years. Advancement in Numerical Climate Prediction, by contrast, has been a total failure and done much harm by falsely alarming the public, scientists, and government leaders to a massive coming CO<sub>2</sub> induced environmental degradation that is not at all realistic. Skillful climate modeling is not possible despite what its many practitioners claim. Most climate modelers have had little experience with real world weather forecasting.

Society, not understanding the physics of climate change, has unfortunately fallen for and accepted the climate doom scenarios of the climate modelers erroneous simulations, ambitious politicians, and environmentalists who have axes they want to grind under the cover of an exaggerated warming threat.

The IPCC reports should be discontinued. These reports are not free of political control. They cannot be objective – and they have grossly exaggerated the CO<sub>2</sub> threat to society.

An independent investigation needs to be conducted of the US research agencies, such as NSF, NASA, DOE and NOAA as to why they have been totally one-sided in supporting pro-AGW studies at the total exclusion of support for research which questions the AGW hypothesis. This is not science but advocacy. Eisenhower's warning on the perils of government sponsored

science being taken over by a class of special interest elitists is coming true – to the detriment of our society and to the very great detriment of American science.

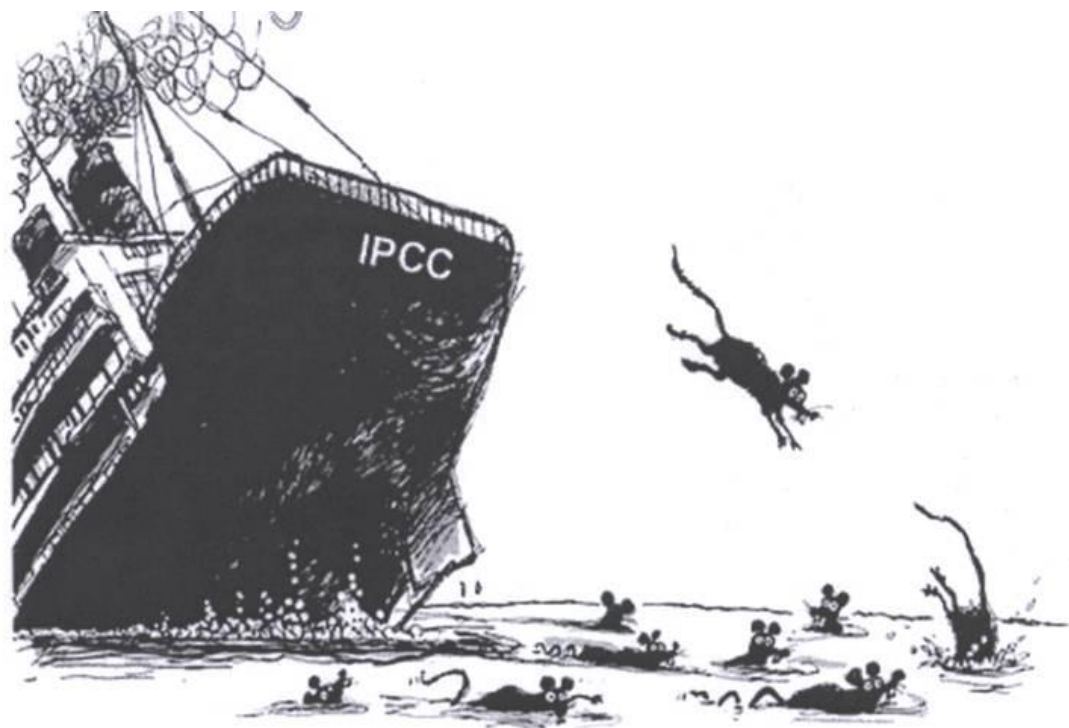
The globe is not going to warm very much ( $\sim 0.3^{\circ}\text{C}$ ) when a doubling of  $\text{CO}_2$  occurs near the end of this century. This small degree of  $\text{CO}_2$  induced warming will, by itself, be more beneficial than harmful for humankind. Natural climate changes will, for the next century, always trump anything that the rising  $\text{CO}_2$  changes could ever bring about. With all the other real and more serious problems facing the world today we should not be so irrationally concerned with the rising levels of  $\text{CO}_2$ .

Renewable energy should be actively studied but not implemented in any substantial way for the large scale generation of electricity. Its 'real' costs will be at least 3-5 times the cost of fossil fuel energy. This is particularly the case with the massive new oil-shale gas deposits now beginning to be uncovered.

Lowering our standard of living through switching to a renewable energy will greatly hinder us in dealing with our serious economic, social, and the many 'real' environmental problems that we face. We should take no action on the AGW question at this time.

This issue will be more ably dealt with by the next generation. They will have had the advantage of witnessing the errors of our generation's acceptance of the greatly overblown warming scenarios. They will also have a better understanding of how organized groups within our society are able to exploit the public's lack of climate understanding for their own benefit.





**The syndicated columnist George Will well states the case in his 6 December '09 column in the Washington Post.**

*“Some climate scientists compound their delusions of intellectual adequacy with messiah complexes. They seem to suppose themselves a small clerisy entrusted with the most urgent truth ever discovered. On it, and hence on them, the planet’s fate depends. So some of them consider it virtuous to embroider facts, exaggerate certitudes, suppress inconvenient data, and manipulate the peer-review process to suppress scholarly dissent and, above all, to declare that the debate is over.”*

## **17. GENERAL BACKGROUND BIBLIOGRAPHY – SOME REFERENCES ARE RELATED BUT NOT REFERRED TOO; A FEW OVERLAP WITH TABLE 3.1**

Chan, J. C., L. Chan, 2006: Comment on “Changes in TC Number, Duration, and Intensity in a Warming Environment.” *Science*, **311**, 1713.

Chang, E. K. M. and Guo, Y, 2007: Is the number of North Atlantic tropical cyclones significantly underestimated prior to the availability of satellite observations? *Geophys. Res. Lett.*, **34**, L14801, doi:10.1029/2007GL030169.

Curry, J. A., P. J. Webster, and G. J. Holland, 2006: Mixing politics and science in testing the hypothesis that greenhouse warming is causing a global increase in hurricane intensity. *Bull. Amer. Meteor. Soc.*, **87**, 1025–1038.

Eastin, M. D., W. M. Gray and P. G. Black, 2005: Buoyancy of convective vertical motions in the inner core of intense hurricanes. Part I: General statistics. *Mon. Wea. Rev.*, **133**, 188-208.

Eastin, M. D., W. M. Gray and P. G. Black, 2005: Buoyancy of convective vertical motions in the inner core of intense hurricanes. Part II: Case studies. *Mon. Wea. Rev.*, **133**, 188-208.

Elsner, J. B., 2006: Evidence in support of the climate change – Atlantic hurricane hypothesis. *Geophys. Res. Lett.*, **33**, L16705, doi:10.1029/2006GL026869.

Elsner, J. B., J. P. Kossin and T. H. Jagger, 2008: The increasing intensity of the strongest TCs. *Nature*, **455**, 92-95.

Emanuel, K., 4 August 2005: Increasing destructiveness of TCs over the past 30 years. *Nature*, **436**, 686-688.

Emanuel, K., R. Sundararajan, and J. Williams, 2008: Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *Bull. Amer. Meteor. Soc.*, **89**, 347-367.

Frank, W. M., 1977a: The structure and energetics of the tropical cyclone, Part I: Storm structure. *Mon. Wea. Rev.*, **105**, 9, 1119-1135.

Frank, W. M., 1977b: The structure and energetics of the tropical cyclone, Part II: Dynamics and energetics. *Mon. Wea. Rev.*, **105**, 9, 1136-1150.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Núñez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and implications. *Science*, **293**, 474-479.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rev.*, **96**, 669-700.

Gray, W. M., 1973: Cumulus convection and larger scale circulations. I. Broadscale and mesoscale considerations. *Mon. Wea. Rev.*, **101**, 839-855.

Gray, W. M., 1975: Tropical Cyclone Genesis. Dept. of Atmospheric Science Paper 234, Colorado State University, Fort Collins, CO, 121 pp.

Gray, W. M., 1979: Hurricanes: their formation, structure and likely role in the tropical circulation. Supplement to Meteorology Over the Tropical Oceans. Published by RMS, James Glaisher House, Grenville Place, Bracknell, Berkshire, D.B. Shaw, (ed.), 155-218.

Gray, W. M., 1979: Observational inferences concerning the occurrence, structure and dynamics of tropical cyclones. *Australian Met. Mag.*, **27**, 4, 197-211.

Gray, W. M., 1982: Tropical cyclone genesis and intensification. Topics in Atmospheric and Oceanographic Sciences, Intense Atmospheric Vortices, (Ed. By L. Bengtsson/J. Lighthill), Springer-Verlag Berlin Heidelberg (ISPN 3-540-11657-5), 3-20.

Gray, W. M., 1984: Atlantic seasonal hurricane frequency. Part I: El Nino and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, **112**, 1649-1668.

Gray, W. M., 1984: Atlantic seasonal hurricane frequency. Part II: Forecasting its variability. *Mon. Wea. Rev.*, **112**, 1669-1683.

Gray, W. M., 1988: Environmental influences on tropical cyclones. *Aust. Meteor. Mag.*, **36**, 3, 127-139.

Gray, W. M., 1993: Tropical cyclone formation and intensity change. Chapter in Tropical Cyclone Disasters, eds. James Lighthill, G. Holland, Z. Zheming, K. Emanuel, Peking University Press, 116-136.

Gray, W. M., 1996: Forecast of global circulation characteristics in the next 25-30 years. 21st Annual Climate Diagnostics and Prediction Workshop (no written report).

Gray, W. M., 1998: The formation of tropical cyclones. *Meteorol. Atmos. Phys.*, **67**, 37-69.

Gray, W. M., 2003: On the transverse circulation of the hurricane. Chapter 11 in Cloud Systems, Hurricanes, and the Tropical Rainfall Measuring Mission (TRMM) – a Tribute to Dr. Joanne Simpson, *Meteorological Monographs*, **29**, 149-164.

Gray, W. M., 2009: Climate change: Driven by the ocean, not human activity. 2nd Annual Heartland Institute Conference on Climate Change, 22 pp. Available on the website: <http://tropical.atmos.colostate.edu/>.

Gray, W.M., J.D. Sheaffer, and C.W. Landsea, 1997: Climate trends associated with multidecadal variability of Atlantic hurricane activity, in Hurricanes. Climate and Socioeconomic Impacts, edited by H. F. Diaz and R. S. Pulwarty, pp. 15-53, Springer-Verlag, New York.

Gray, W. M. and P. J. Klotzbach, 2011: Have Increases in CO<sub>2</sub> Contributed to the Recent Large Upswing in Atlantic Basin Major Hurricanes since 1995? *Evidence-Based Climate Science*. (pp. 223-249). Elsevier Inc. (ISBN: 9780123859563).

Gray, W. M. and B. Schwartz, 2011: The association of albedo and OLR radiation with variations of precipitation – implications for AGW. Presented at the 91<sup>st</sup> meeting of the AMS Conference, Seattle, WA, January 23-27, 2011.

Grossmann, I. and P. J. Klotzbach, 2009: A review of North Atlantic modes of natural variability and their driving mechanisms. *J. Geophys. Res.*, **114**, D24107, doi:10.1029/2009JD012728.

Holland and Webster, 2007: Heightened tropical cyclone activity in the North Atlantic: Natural variability or climate trend? *Phil. Trans. R. Soc. A* doi: 10.1098/rsta.2007.2083

Hoyos, C. D., P. A. Agudelo, P. J. Webster and J. A. Curry, 2006: Deconvolution of the factors contributing to the increase in global hurricane intensity, *Science*, **312** (5770), 94-97.

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), 2007.

Klotzbach, P. J., 2006: Trends in global tropical cyclone activity over the past twenty years (1986-2005). *Geophys. Res. Lett.*, **33**, L10805, doi:10.1029/2006GL025881

Klotzbach, P. J. and W. M. Gray, 2006: Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc.*, **87**, 1325-1333.

Klotzbach, P. J. and W. M. Gray, 2008: Multidecadal variability in North Atlantic TC activity. *J. Climate*, **21**, 3929-3935.

Knutson, T. R., R. E. Tuleya, and Y. Kurihara, 1998: Simulated increase of hurricane intensities in a CO<sub>2</sub>-warmed climate. *Science*, **279**, 1018-1020.

Knutson, T. R., J. McBride, J. Chan, K. A. Emanuel, G. Holland, C. Landsea, Isaac Held, J. Kossin, A. K. Srivastava, and M. Sugi, 2010: TCs and climate change. *Nature Geoscience*, **3**, doi:10.1038/ngeo779.

Kossin, J. P., Knapp, K. R., Vimont, D. J., Murnane, R. J., and Harper, B. A., 2007: A globally consistent reanalysis of hurricane variability and trends. *Geophys. Res. Lett.*, **34**, L04815, doi:10.1029/2006GL028836.

Landsea, C. W., 2005: Hurricanes and global warming. *Nature*, **438**, E11-13, doi:10.1038/nature04477.

Landsea, C. W., B. A. Harper, K. Hoarau, and J. A. Knaff, 2006: Can we detect trends in extreme TCs? *Science*, **313**, 452-454.

Landsea, C. W., 2007: Counting Atlantic TCs back to 1900. *EOS*, **88**, 197 & 2002.

Lee, C.-S., 1984: The bulk effects of cumulus momentum transports in tropical cyclones. *J. Atmos. Sci.*, **41**, 16, 590-603.

- Lee, C.-S., 1989: Observational analysis of tropical cyclogenesis in the western North Pacific: I: Structural evolution of cloud clusters. *J. Atmos. Sci.*, **46**, 16, 2580-2598.
- Lee, C.-S., 1989: Observational analysis of tropical cyclogenesis in the western North Pacific: II: Budget analysis. *J. Atmos. Sci.*, **46**, 16, 2599-2616.
- Lighthill, J., G. Holland, W. Gray, C. Landsea, G. Craig, J. Evans, Y. Kurihara and C. Guard, 1994: Global climate change and tropical cyclones. *Bull. Amer. Meteor. Soc.*, **75**, 2147-2157.
- Lopez, R. E., 1973a: A parametric model of cumulus convection. *J. Atmos. Sci.*, **30**, 1354-1373.
- Lopez, R. E., 1973b: Cumulus convection and larger-scale circulations, Part II: Cumulus and meso-scale interactions. *Mon. Wea. Rev.*, **101**, 856-870.
- Mann, M.E., Emanuel, K.A., 2006: Atlantic Hurricane Trends linked to Climate Change. *Eos*, **87**, 24, p 233, 238, 241.
- Mann, M.E., Sabbatelli, T.A., Neu, U., 2007: Evidence for a Modest Undercount Bias in Early Historical Atlantic Tropical Cyclone Counts. *Geophys. Res. Lett.*, **34**, L22707, doi:10.1029/2007GL031781.
- Maue, R.N., 2010: 2010 Global Tropical Cyclone Activity Update.
- Maue, R. N. (2011), Recent historically low global tropical cyclone activity. , *Geophys. Res. Lett.*, **38**, L14803, 6 PP., 2011 doi:10.1029/2011GL047711.
- McBride, J. L., 1981: Observational analysis of tropical cyclone formation, Part I: Basic description of data sets. *J. Atmos. Sci.*, 1117-1131.
- McBride, J. L. and R. Zehr, 1981: Observational analysis of tropical cyclone formation, Part II: Comparison of non-developing versus developing systems. *J. Atmos. Sci.*, 1132-1151.
- McBride, J. L., 1981: Observational analysis of tropical cyclone formation, Part III: Budget analysis. *J. Atmos. Sci.*, 1152-1166.
- Merrill, Robert T., 1984: A Comparison of Large and Small Tropical Cyclones. *Mon. Wea. Rev.*, **112**, 1408–1418.
- C. Mooney, 2005: *The Republican War on Science*, Perseus, 342 pp.
- C. Mooney, 2007: *Storm World: Hurricanes, Politics, and the Battle over Global Warming*, Harcourt, 392 pp.
- C. Mooney and S. Kirshenbaum, 2009: *Unscientific America: How Scientific Illiteracy Threatens Our Future*, Basic Books, 224 pp.

Pielke, R.A., Jr., 2005: Are there trends in hurricane destruction? *Nature*, **438**, E11, doi:10.1038/nature04477.

Pielke, Jr., R. A. and C. W. Landsea 1998: Normalized Hurricane Damages in the United States: 1925-1995. *Weather and Forecasting*, **13**, 621-631

Sabbatelli, T. A. and M. E. Mann, 2007: The influence of climate state variables on Atlantic TC occurrence rates. *J. Geophys. Res.*, **112**, D17114.

Santer, B. D., Taylor, K. E., Wigley, T. M., Johns, T. C., Jones, P. D., Karoly, D. J., Mitchell, J.F.B., Oort, A. H., Penner, J. E., Ramaswamy, V., Schwarzkopf, M. D., Stouffer, R. J., & Tett, S. (1996). A search for human influence on the thermal structure of atmosphere. *Nature*, **382**, 139-146.

Santer, B.D., T.M.L. Wigley, P.J. Gleckler, C. Bonfils, M.F. Wehner, K. AchutaRao, T.P. Barnett, J.S. Boyle, W. Brüggemann, M. Fiorino, N. Gillett, J.E. Hansen, P.D. Jones, S.A. Klein, G.A. Meehl, S.C.B. Raper, R.W. Reynolds, K.E. Taylor, and W.M. Washington, 2006: Forced and unforced ocean temperature changes in Atlantic and Pacific tropical cyclogenesis regions. *Proc. Natl. Acad. Sci.*, **103**, 13905-13910, doi:10.1073/pnas.0602861103.

Santer, B. D., P. W. Thorne, L. Haimberger, K. E. Taylor, T.M.L. Wigley, J. R. Lanzante, S. Solomon, M. Free, P. J. Gleckler, P. D. Jones, T. R. Karl, S. A. Klein, C. Mears, D. Nychka, G. A. Schmidt, S. C. Sherwood, and F. J. Wentz, 2008: Consistency of modelled and observed temperature trends in the tropical troposphere. *International Journal of Climatology*, **28**, 1703-1722.

Striver, R., and M. Huber, 2006: Low frequency variability in globally integrated tropical cyclone power dissipation. *Geophys. Res. Lett.*, **33**, L11705, doi:10.1029/2006GL026167.

Trenberth, K., 2007: Warmer Oceans, Stronger Hurricanes. *Scientific American*, 44-51, July.

Trenberth, K. E., and D. J. Shea, 2006: Atlantic hurricanes and natural variability in 2005. *Geophys. Res. Lett.*, **33**, L12704, doi:10.1029/2006GL026894.

Vecchi, G. A. and B. J. Soden, 2007: Effect of remote sea surface temperature change on TC potential intensity. *Nature*, **450**, 1066-1071

Weatherford, C. L. and W. M. Gray, 1988: Typhoon structure as revealed by aircraft reconnaissance. Part I: Data analysis and climatology. *Mon. Wea. Rev.*, **116**, 1032-1043.

Weatherford, C. L. and W. M. Gray, 1988: Typhoon structure as revealed by aircraft reconnaissance. Part II: Structural variability. *Mon. Wea. Rev.*, **116**, 1044-1056.

P. Webster, G. Holland, J. Curry and H-C. Chang, 2005: Changes in TC number, duration, and intensity in a warming environment. *Science*, **309**, 1844-1846.

Williams, K. and W. M. Gray, 1973: Statistical analysis of satellite observed cloud clusters in the western Pacific. *Tellus*, **21**, 313-336.

R. Zehr, 1976: Tropical Disturbance Intensification. Dept. of Atmospheric Science Paper 259, Colorado State University, Fort Collins, CO, 91 pp.

## **18. ACKNOWLEDGEMENT**

I appreciate my many interactions and discussions on this topic with Barry Schwartz and a number of my other colleagues. I thank Phil Klotzbach for much data checking and manuscript review. Amie Hedstrom's extensive and talented manuscript support was indispensable. The financial support of this report and much of the research discussed came from my personal resources. No government or fossil-fuel support were involved. I appreciate Science and Public Policy Institute (SPPI) and its Director, Robert Ferguson, for their duplication and distribution of this report.

## **19. APPENDICES**

For those seeking more background information on this topic I have attached various related material in this Appendix.

- A. **(1)** Emanuel's 2005 *Nature* paper and Gray's response letter to the Editor (which was not accepted).
- (2)** Webster-Holland-Curry-Chang, 2005 *Science* paper and Gray's response letter to the Editor (which was not accepted).
- B. Hurricane specialist Chris Landsea's resignation letter from the IPCC-AR4 committee (2005).
- C. Wall Street Journal article (2 Feb. '06) titled "Hurricane Debate Shatters Civility of Weather Science" by Valerie Bauerlein.
- D. William M. Gray's Vita.

## APPENDIX A

The two papers that received unusually high amounts of publicity, extensive references in journal literature, and formed the basis for the IPCC-AR4 (2007) report on tropical cyclones. These two papers were:

(1) Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, **436**, 686-688.

(2) P. Webster, G. Holland, J. Curry and H-C. Chang, 16 September 2005: Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, **309**, 1844-1846.

Both of these papers had fundamental observation and conceptual errors. They should never have been published let alone serve as the basis for the IPCC-AR4 tropical cyclone discussion.

My opinion of the relevance of these papers was solicited by the media in 2005-06. I made strong criticism of these papers at the time of their publication and wrote rebuttal letters to both *Nature* and *Science*. But both journals rejected my comments.

Comments on: "Increasing destructiveness of tropical cyclones over the past 30 years"  
by Kerry Emanuel, *Nature*, **31** July 2005, Vol. 436, pp. 686-688

William M. Gray  
Department of Atmospheric Science  
Colorado State University  
Fort Collins, CO 80523 USA

Submitted to *Nature* as Communication Arising  
19 October 2005

**REJECTED FOR PUBLICATION**

### ***ABSTRACT***

**This paper concludes that global tropical cyclone net power dissipation [(or friction times wind) - taken to be proportional to the sum of each cyclone's individual 6-hour track period maximum wind speed cubed ( $\sim V_{\max}^3$ )] has undergone large (more than doubled) increases over the last 30 years. The author associates these frictional energy dissipation increases with rising mean sea surface temperatures (SSTs) and implies that these SST increases may, in part, be related to human activity. But, the author's results and his interpretation of his calculations are not realistic.**

### ***DISCUSSION***

This paper's conclusions are based on an analysis of poorly documented and biased tropical cyclone (TC) maximum wind ( $V_{\max}$ ) data from the Northwest (NW) Pacific. This study presents a sum of each tropical cyclone's maximum winds - a very hard measurement to realistically obtain over a 3-5 decade period of changing maximum wind measurement techniques. The author then cubes these maximum wind speeds ( $V_{\max}^3$ ) of questionable accuracy. Such a cubing process greatly exaggerates any errors in the original  $V_{\max}$  estimate.

The author has utilized the official best track NW Pacific tropical cyclone (TC)  $V_{\max}$  values over the last 50 years. He has made corrections to some of the  $V_{\max}$  values and has accepted others as realistic. His analysis has many problems. It is known that there are long-period systematic biases in the NW Pacific maximum wind ( $V_{\max}$ ) values because of the methodological changes in how the NW Pacific maximum wind estimates have been made. The author tried to account for these measurement technique differences, but his method of doing so was not right. It was his faulty corrections for the long term biases in the NW Pacific data set which led to his invalid calculations that TC energy dissipation had shown large increases in recent years.

Prior to 1973, maximum winds ( $V_{\max}$ ) in the NW Pacific could not be reliably measured. They were estimated from aircraft central pressure and flight crew visual estimations of wave-spray characteristics. Crews had a tendency to exaggerate their maximum wind estimates. A guideline to determining maximum winds ( $V_{\max}$ ) from measured central pressure in general use at the Joint-Typhoon Warning Center (JTWC) until the early 1970s was  $V_{\max} = 16(1010 - P_c)^{0.5}$ , where  $P_c$  is central pressure in millibars and  $V_{\max}$  is maximum wind in knots.

To correct what appeared, at the time, to be overestimations of  $V_{\max}$ , Atkinson and Holliday (1977), while engaged in forecasting duties at JTWC, devised a new maximum wind-central pressure relationship scheme which was used as a guide for later  $V_{\max}$  determination. This wind-pressure relationship was applied between 1973-1986. This new formula specified  $V_{\max} = 6.7 (1010 - P_c)^{0.644}$ . These newer Atkinson-Holliday (AH) estimates gave central pressure-determined maximum wind values which are now known to be too low. For a typhoon with a MSLP of 950 mb, the  $V_{\max}$  difference by these two techniques is 32 percent lower with the Atkinson-Holliday (AH) scheme than the pre-1973 scheme. This would lead to a 232 percent higher value of  $V_{\max}^3$  with the earlier pre-1973 method than with the later (1973-86) AH method.

The AH scheme substantially underestimated  $V_{\max}$  for all typhoons. This resulted in a significant underestimate of Northwest Pacific cyclone  $V_{\max}$  values between 1973-1986. For instance, in the 6-year period prior to 1973 the average seasonal number of typhoons with maximum winds above 100 and 130 knots was over twice as much as during the average 6-year period of 1973-1978. The average annual number of super typhoons in the West Pacific between 1950-1972 and 1987-2004 was 5.3 and 4.9. In the AH period of 1973-86, it was only 2.3. Yet West Pacific typhoon activity in the 1973-86 period showed no apparent differences from earlier or later period activity. The AH scheme was discontinued after 1986 when aircraft reconnaissance in the NW Pacific was terminated, and central pressures could no longer be directly measured.  $V_{\max}$  values have since been obtained solely from satellite. The Dvorak satellite TC intensity scheme (1975, 1984) is known to give systematic higher  $V_{\max}$  estimates than the AH scheme. Knaff and Zehr's (2005) recent analysis shows that the Dvorak satellite (1975, 1984) scheme for the estimation of  $V_{\max}$  (used in the Pacific since 1987) gives, on average, about 7.5 m/s higher  $V_{\max}$  value than the AH scheme for all wind speed categories. There is no question that the Dvorak scheme is superior to the AH scheme. The differences between the Dvorak and the AH schemes causes large differences in  $V_{\max}^3$ . For 7.5 m/s wind differences of 32.5 m/s for Dvorak versus 25 m/s for AH, the cubed ratio of the Dvorak to the AH maximum wind speed is 2.2. For higher  $V_{\max}$  values (say 57.5 vs. 50 m/s) this ratio is 1.5. There are many more TC time periods in Emanuel's analysis of the lower  $V_{\max}$  values when this ratio of the cubed  $V_{\max}$  of the satellite to the AH is close to 2 to 1.

Most of the large increase in Emanuel's NW Pacific TC energy dissipation calculations from the early 1970s to the early 2000s can be explained by the cubed differences of the  $V_{\max}$  estimates between the more recent (since 1987) Dvorak pure satellite scheme for  $V_{\max}$  and the earlier (1973-1986) period when the AH aircraft scheme was used.

Another major problem with Emanuel's results is his assumption that a measurement of  $V_{\max}^3$  is directly related to the net frictional energy dissipation of the cyclone's entire broad scale

circulation. A cyclone's outer radius area is vastly larger than its inner core of high wind speed and can bring about more net wind energy dissipation than the inner-core. Emanuel's use of  $V_{\max}^3$  for an estimation of TC net broad scale energy dissipation is not a satisfactory assumption.

In the Atlantic,  $V_{\max}$  has been more reliably measured with aircraft. But increases in  $V_{\max}^3$  and longer cyclone tracks have occurred only in the last 11 years (1995-2005) and not over the last 30 years as this study implies. Most of Emanuel's 30-year increase in wind energy dissipation occurs from his combination of the Atlantic and Pacific data sets where the Pacific has nearly three times as many tropical cyclones as the Atlantic.

There was a lower Atlantic net  $V_{\max}^3$  between 1975 and 1994, at a time that global SST's were rising. Much higher  $V_{\max}^3$  values occurred in the 1950s and 1960s when global mean SST values were undergoing a modest decrease. It is only in the last decade that there have been increases in Atlantic  $V_{\max}$  and track length. The last-decade Atlantic increases in hurricane activity can be directly associated with the large increase in the strength of the Atlantic Ocean Thermohaline circulation (THC) – the so called positive phase of the Atlantic multi-decadal oscillation (AMO). Multi-decadal variations in Atlantic sea surface temperatures, associated with multi-decadal oscillations in Atlantic hurricane activity, have also been documented in Greenland ice-core temperature records going back thousands of years. The increase in  $V_{\max}$  in the Atlantic over the last decade (1995-2005) should terminate when the thermohaline circulation (THC) weakens in the coming decades. Atlantic net TC frictional energy wind dissipation will then be reduced.

### ***VARIATION IN MAJOR HURRICANE NUMBERS DURING THE LAST TWO DECADES OF GLOBAL WARMING***

The NCEP/NCAR reanalysis of global mean surface temperature and global SSTs shows a rise in temperature over the last 10 years in comparison with the mean global surface temperature and SST of the prior 10 years of 1985-1994. Between 1995-2004, average global surface temperatures have been observed to be about 0.4°C higher than the earlier 10-year period of 1985-1994. Table 1 shows the number of observed major hurricanes (Cat. 3-4-5) around the globe (excluding the Atlantic) between these two 10-year periods. Major hurricane activity has not gone up in the more recent 10-year period when global surface temperatures have been higher.

There have been hurricane periods in the Atlantic in the past which have been just as active as the current period. A comparison of the last 15 years of hurricane activity with an earlier 15-year period from 1950-64 shows no significant difference in either Category 1-2 hurricanes or of major (Category 3-4-5) hurricanes.

It should also be noted that Emanuel's large increases in net rate of TC energy dissipation (his PDI) was derived from only two of the seven global tropical cyclone basins. Data from the Northeast Pacific and the other tropical cyclone basins (North Indian Ocean and the Southern Hemisphere's three TC basins) were not a part of his study. As Table 1 indicates, these other

tropical cyclone basins do not show major hurricane increases over the last two 10-year periods.

*Table 1. Comparison of observed major (Cat. 3-4-5) tropical cyclones in all global basins (except the Atlantic) in the two most recent 10-year periods of 1985-94 and 1995-2004.*

	1985-1994 (10 years)	1995-2004 (10 years)
North & South Indian Ocean	45	50
South Pacific & Australia	44	41
NW Pacific	88	87
Northeast Pacific	41	40
GLOBE TOTAL (excluding Atlantic)	218	218

### **SUMMARY**

There is no physical basis for assuming that global tropical cyclone intensity or frequency is necessarily related to global mean surface temperature changes of less than  $\pm 0.5^{\circ}\text{C}$ . As the ocean surface warms, global upper air temperatures also increase to maintain conditionally unstable lapse-rates and global rainfall rates at their required values. Seasonal and monthly variations within individual storm basins show only very low correlations of sea surface temperature (SST) with monthly, seasonal, and yearly variations of hurricane activity. These correlations are typically of the order of about 0.3, explaining only about 10 percent of the variance. Other factors such as tropospheric vertical wind shear, surface pressure, low level vorticity, mid-level moisture, etc. play more dominant roles in explaining hurricane variability on these shorter time scales. Although there has been a general global warming over the last 10 years, the SST increases in the individual tropical cyclone basins have been smaller (about half), and according to the observations have not brought about any significant increases in global major tropical cyclones except for the Atlantic where a shift has been made to the positive phase of the Atlantic multi-decadal oscillation. No credible observational evidence is available or likely will be available in the next few decades which will be able to directly associate global temperature change to changes in global tropical cyclone frequency and intensity.

**Acknowledgement:** I would like to acknowledge beneficial discussions on this topic with John Knaff and Philip Klotzbach.

## REFERENCES

Atkinson, G.D. and C.R. Holliday, 1977: Tropical cyclone minimum sea level pressure/maximum sustained wind relationship for the western North Pacific. Mon. Wea. Rev., **105**, 421-427.

Dvorak, V.F., 1975: Tropical cyclone intensity analysis and forecasting from satellite imagery. Mon. Wea. Rev., **103**, 420-430.

Dvorak, V.F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Technical Report NESDIS 11, 45 pp.

Knaff, J.A. and R.M. Zehr, 2005: Re-examination of tropical cyclone pressure wind relationships (being submitted for publication).

Technical Comments on the recently published paper in *Science* by Webster, Holland, Curry, and Chang, titled “Changes in tropical cyclone number, duration, and intensity in a warming environment” (16 September 2005, Vol. 309, pp. 1844-1846, [www.sciencemag.org](http://www.sciencemag.org))

by

William M. Gray  
Department of Atmospheric Science  
Colorado State University  
Fort Collins, CO 80523 USA  
26 October 2005

**REJECTED FOR PUBLICATION**

### **ABSTRACT**

This recent *Science* paper by Webster, Holland, Curry and Chang indicates that the global number of Category 4-5 hurricanes have increased in the last 15 years (1990-2004) in comparison with the prior 15-year period of 1975-1989. Global mean surface temperature in the later period has been about 0.3°C higher than in the earlier period. The authors' imply that their observed rise in global Category 4-5 hurricanes are related to higher global temperatures which may have an anthropogenic greenhouse gas component. I do not agree that global Category 4-5 tropical cyclone activity has been rising, except in the Atlantic over the last 11 years. The recent Atlantic upsurge in Category 4-5 hurricanes is not found in the other global basins and is due to processes other than global surface temperature increase.

### **DISCUSSION**

I cannot accept the accuracy of the measurements of global Category 4-5 hurricanes during 1975-1989 as indicated in the author's Table 1. This earlier 15 year global data set would not have been able to accurately delineate Category 4-5 hurricanes from Category 3 hurricanes or even at times from Category 1-2 hurricanes.

In the late 1970s I visited all the global tropical cyclone centers and observed their satellite capabilities and the training of their forecasters as part of a World Meteorological Organization (WMO) tropical cyclone survey trip that I was commissioned to make. The satellite tools and forecaster training in the tropical cyclone regions of the Indian Ocean and Southern Hemisphere during the 1975-1989 period was not adequate for the task of objectively distinguishing Category 4-5 hurricanes from other hurricane intensities. Table 1 of the Webster et al. paper indicates that there were 32 Indian Ocean and South Pacific Category 4-5 tropical cyclones in 1975-89 and 79 (247 percent more) during the 15-year period of 1990-2004. Such large increases are not reasonable given the fact that the frequencies of the weaker cyclones in these basins did not show much difference.

It would be instructive to observe the increase of major hurricanes (Category 3-4-5) during the last 20 years when satellite technology had improved. It would be easier to distinguish Category 3-4-5 hurricanes as compared to just Category 4-5 hurricanes alone. Also, the largest rise in global surface air temperature occurred during the last 10 years. The NOAA-NCEP reanalysis of global mean temperature differences between the last two 10-year periods show that the last 10 years (1995-2004) of global surface temperature have been about 0.4°C warmer than the earlier 10-year period of 1985-1994. If there was an influence of global warming on major hurricane activity, one would expect to see this increase represented by greater numbers of global major hurricanes during the last 10 years in comparison with the earlier 10-year period.

Table 1 shows the number of measured major hurricanes (Cat. 3-4-5) around the globe (excluding the Atlantic). Note that there has been no apparent difference in reported major (Cat. 3-4-5) hurricanes between these two 10-year periods despite the globe being about 0.4°C warmer in the recent period.

*Table 1. Comparison of observed major (Cat. 3-4-5) tropical cyclones in all global basins (except the Atlantic) in the two most recent 10-year periods of 1985-94 and 1995-2004.*

	1985-1994 (10 Years)	1995-2004 (10 Years)
North & South Indian Ocean	45	50
South Pacific & Australia	44	41
NW Pacific	88	87
Northeast Pacific	41	40
GLOBE TOTAL (excluding Atlantic)	218	218

By contrast, the Atlantic has seen a very large increase in major hurricanes between 1995-2004 in comparison to the previous 10-year period of 1985-1994. This large increase in Atlantic major hurricanes during the more recent period is a result of the multi-decadal increase in the Atlantic Ocean thermohaline circulation (THC) and is not due to global temperature increase. Changes in salinity are believed to be the driving mechanism. These multi-decadal changes have also been termed the Atlantic Multi-Decadal Oscillation (AMO).

There have been past hurricane periods in the Atlantic which have had just as many major hurricanes and Category 4-5 hurricanes as in recent years. A comparison of the last 15 years of hurricane activity with an earlier 15-year period from 1950-64 shows no significant difference in major hurricanes or Category 4-5 hurricanes even though the global surface temperatures were colder and there was a general global cooling during 1950-64 as compared with global warming during 1990-2004.

The most reliable comparison of Category 4-5 hurricanes that can likely be made is to compare the last ten years (1995-2004) with the prior ten years (1985-1994) for North Pacific storm areas monitored by the US and Japan. The two North Pacific basins do not indicate that the number of hurricanes of Category 4-5 intensity have increased in the last 10 years when global surface temperatures have risen. Measured Category 4-5 numbers in the North Pacific were 101 in the 1985-1994 period and 95 in the more recent 1995-2004 period – no significant difference.

### ***SUMMARY***

Global measurements do not support the contention of Webster, et al. that global numbers of Category 4-5 hurricanes have become more frequent in the last 15 years. There is no physical basis for assuming that global tropical cyclone intensity or frequency is necessarily related to global mean surface temperature changes of less than  $\pm 0.5^{\circ}\text{C}$ . As the ocean surface warms, so does the global upper air temperature rise to maintain conditionally unstable lapse-rates and global rainfall rates at their required values. Seasonal and monthly variations of SST within the individual storm basins show only very low correlations with monthly, seasonal, and yearly variations of hurricane activity. These correlations typically explain only about 10 percent of the hurricane variance. Other factors such as tropospheric vertical wind shear, surface pressure, low level vorticity, mid-level moisture, etc. play more dominant roles in explaining hurricane variability.

Although there has been a general global warming over the last 30 years and particularly over the last 10 years, the SST increases in the individual tropical cyclone basins have been smaller (about half) than for the globe as a whole and have not brought about any significant increases in global major hurricane activity except for the Atlantic which, as discussed, has multi-decadal oscillations which are driven by changes in salinity. No credible observational evidence is available or likely will be available in the next few decades which will be able to directly associate global temperature change to changes in global Category 4-5 hurricane frequency and intensity.

## **APPENDIX B**

Chris Landsea's ICPP-AR4 resignation letter.

### **AN OPEN LETTER TO THE COMMUNITY FROM CHRIS LANDSEA (RESIGNATION LETTER OF CHRIS LANDSEA FROM IPCC)**

Dear colleagues,

After some prolonged deliberation, I have decided to withdraw from participating in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). I am withdrawing because I have come to view the part of the IPCC to which my expertise is relevant as having become politicized. In addition, when I have raised my concerns to the IPCC leadership, their response was simply to dismiss my concerns.

With this open letter to the community, I wish to explain the basis for my decision and bring awareness to what I view as a problem in the IPCC process. The IPCC is a group of climate researchers from around the world that every few years summarize how climate is changing and how it may be altered in the future due to manmade global warming. I had served both as an author for the Observations chapter and a Reviewer for the 2nd Assessment Report in 1995 and the 3rd Assessment Report in 2001, primarily on the topic of tropical cyclones (hurricanes and typhoons). My work on hurricanes and tropical cyclones more generally, has been widely cited by the IPCC. For the upcoming AR4, I was asked several weeks ago by the Observations chapter Lead Author---Dr. Kevin Trenberth---to provide the write-up for Atlantic hurricanes. As I had in the past, I agreed to assist the IPCC in what I thought was to be an important and politically-neutral determination of what is happening with our climate.

Shortly after Dr. Trenberth requested that I draft the Atlantic hurricane section for the AR4's Observations chapter, Dr. Trenberth participated in a press conference organized by scientists at Harvard on the topic "Experts to warn global warming likely to continue spurring more outbreaks of intense hurricane activity" along with other media interviews on the topic. The result of this media interaction was widespread coverage that directly connected the very busy 2004 Atlantic hurricane season as being caused by anthropogenic greenhouse gas warming occurring today. Listening to and reading transcripts of this press conference and media interviews, it is apparent that Dr. Trenberth was being accurately quoted and summarized in such statements and was not being misrepresented in the media. These media sessions have potential to result in a widespread perception that global warming has made recent hurricane activity much more severe.

I found it a bit perplexing that the participants in the Harvard press conference had come to the conclusion that global warming was impacting hurricane activity today. To my knowledge, none of the participants in that press conference had performed any research on hurricane variability, nor were they reporting on any new work in the field. All previous and current research in the area of hurricane variability has shown no reliable, long-term trend up in the frequency or intensity of tropical cyclones, either in the Atlantic or any other basin. The IPCC assessments in 1995 and 2001 also concluded that there was no global warming signal found in the hurricane record.

Moreover, the evidence is quite strong and supported by the most recent credible studies that any impact in the future from global warming upon hurricane will likely be quite small. The latest results from the Geophysical Fluid Dynamics Laboratory (Knutson and Tuleya, *Journal of Climate*, 2004) suggest that by around 2080, hurricanes may have winds and rainfall about 5% more intense than today. It has been proposed that even this tiny change may be an exaggeration as to what may happen by the end of the 21st Century (Michaels, Knappenberger, and Landsea, *Journal of Climate*, 2005, submitted).

It is beyond me why my colleagues would utilize the media to push an unsupported agenda that recent hurricane activity has been due to global warming. Given Dr. Trenberth's role as the IPCC's Lead Author responsible for preparing the text on hurricanes, his public statements so far outside of current scientific understanding led me to concern that it would be very difficult for the IPCC process to proceed objectively with regards to the assessment on hurricane activity. My view is that when people identify themselves as being associated with the IPCC and then make pronouncements far outside current scientific understandings that this will harm the credibility of climate change science and will in the longer term diminish our role in public policy.

My concerns go beyond the actions of Dr. Trenberth and his colleagues to how he and other IPCC officials responded to my concerns. I did caution Dr. Trenberth before the media event and provided him a summary of the current understanding within the hurricane research community. I was disappointed when the IPCC leadership dismissed my concerns when I brought up the misrepresentation of climate science while invoking the authority of the IPCC. Specifically, the IPCC leadership said that Dr. Trenberth was speaking as an individual even though he was introduced in the press conference as an IPCC lead author; I was told that that the media was exaggerating or misrepresenting his words, even though the audio from the press conference and interview tells a different story (available on the web directly); and that Dr. Trenberth was accurately reflecting conclusions from the TAR, even though it is quite clear that the TAR stated that there was no connection between global warming and hurricane activity. The IPCC leadership saw nothing to be concerned with in Dr. Trenberth's unfounded pronouncements to the media, despite his supposedly impartial important role that he must undertake as a Lead Author on the upcoming AR4.

It is certainly true that "individual scientists can do what they wish in their own rights", as one of the folks in the IPCC leadership suggested. Differing conclusions and robust debates are certainly crucial to progress in climate science. However, this case is not an honest scientific discussion conducted at a meeting of climate researchers. Instead, a scientist with an important role in the IPCC represented himself as a Lead Author for the IPCC has used that position to promulgate to the media and general public his own opinion that the busy 2004 hurricane season was caused by global warming, which is in direct opposition to research written in the field and is counter to conclusions in the TAR. This becomes problematic when I am then asked to provide the draft about observed hurricane activity variations for the AR4 with, ironically, Dr. Trenberth as the Lead Author for this chapter. Because of Dr. Trenberth's pronouncements, the IPCC process on our assessment of these crucial extreme events in our climate system has been subverted and compromised, its neutrality lost. While no one can "tell" scientists what to say or not say (nor am I suggesting that), the IPCC did select Dr. Trenberth as a Lead Author and entrusted to him to carry out

this duty in a non-biased, neutral point of view. When scientists hold press conferences and speak with the media, much care is needed not to reflect poorly upon the IPCC. It is of more than passing interest to note that Dr. Trenberth, while eager to share his views on global warming and hurricanes with the media, declined to do so at the Climate Variability and Change Conference in January where he made several presentations. Perhaps he was concerned that such speculation---though worthy in his mind of public pronouncements---would not stand up to the scrutiny of fellow climate scientists.

I personally cannot in good faith continue to contribute to a process that I view as both being motivated by pre-conceived agendas and being scientifically unsound. As the IPCC leadership has seen no wrong in Dr. Trenberth's actions and have retained him as a Lead Author for the AR4, I have decided to no longer participate in the IPCC AR4.

Sincerely,

Chris Landsea

17 January 2005

## APPENDIX C



February 2, 2006

PAGE ONE

*Cold Front*  
**Hurricane Debate  
Shatters Civility  
Of Weather Science**

**Worsened by Global Warming?  
Spats Are So Tempestuous,  
Sides Are Barely Talking**

**Charge of 'Brain Fossilization'**

**By VALERIE BAUERLEIN**  
Staff Reporter of THE WALL STREET JOURNAL  
*February 2, 2006; Page A1*

The 2,000-plus scientists at this week's annual meeting of the American Meteorological Society had plenty to talk about, from last year's droughts to flash floods and wildfires. But the biggest question at the meeting in Atlanta -- why last hurricane season was the worst since recordkeeping began 151 years ago -- was almost too hot to handle.



**William Gray**

William Gray, America's most prominent hurricane scientist and an ardent foe of the belief that global warming has worsened hurricanes, was supposed to join a panel discussing the storms. So was Greg Holland of the National Center on Atmospheric Research -- who disagrees with Dr. Gray. But the organizers withdrew the invitations after deciding the dispute had grown so nasty it was too risky to put the two in the same room.

"It was looking like it would totally dominate everything else," says Joe Schaefer, a planner and the director of the National Weather Service's Storm Prediction Center.

"To hell with it, I'm not going" to Atlanta, said Dr. Gray, a Colorado State University professor of atmospheric science, after learning of the cancellation before the conference. He didn't attend.

His adversary Dr. Holland is among a group of prominent scientists who argue that the recent burst of powerful storms isn't part of a normal pattern. In a recent article, he and co-authors said that global warming caused by human activity, while not affecting the number of hurricanes, appears to be causing more of them to be very intense. Dr. Holland went to the meeting despite the cancellation of his joint appearance with Dr. Gray and presented his paper's conclusions during a session on a wide variety of weather issues.



**Greg Holland**

What is going on with hurricanes like Katrina and the subsequent Wilma, which was the strongest ever recorded in the Atlantic, matters urgently to millions of people wondering whether coastal areas are safe. Insurers and other companies are trying to calculate future risks of operating in the vulnerable regions. And policy makers are wrestling with whether to rebuild some shattered communities.

Dr. Gray, who is 76 years old, has been studying storms for nearly a half-century. He is the author of seminal early models for predicting the atmospheric conditions that lead to storms and was a mentor to 70 doctoral and master's students -- including Dr. Holland.

Dr. Gray hasn't been shy about firing back at his critics. After Judith Curry, a climatologist at Georgia Institute of Technology in Atlanta, co-wrote a paper linking global warming and hurricane intensity, he said: "Judy Curry just doesn't know what she's talking about."

Dr. Curry, in an interview at her Georgia Tech office, said Dr. Gray has "brain fossilization." She added: "Nobody except a few groupies wants to hear what he has to say."

Dr. Gray has said on his Web site and has testified to Congress that recent storms' intensity wasn't fueled by human-induced global warming. Natural factors, he says, such as the presence of upper-air currents that can bat storms from side to side, helped steer them ashore and thus made them more destructive. Dr. Gray believes the current era of high activity will eventually end as a result of changes in salinity and currents in the Atlantic. Sometime in the next decade or two, he predicts, the earth will enter a cooling period, as it did in the 1950s.

In October 2004, Dr. Gray's views faced a head-on challenge from Kevin Trenberth, head of climate analysis at the National Center for Atmospheric Research, a prominent institute in Boulder, Colo., where Dr. Holland also works. At a news conference convened by Harvard Medical School's Center for Health and the Global Environment, Dr. Trenberth outlined his position that the spate of hurricanes that slammed the U.S. in 2004 might be linked to global warming caused by humans. He said rising temperatures weren't necessarily triggering more hurricanes but might be causing stronger ones, because as oceans warm they create more water vapor, the fuel for hurricanes.

That news conference roiled the world of weather scientists, several of whom thought Dr. Trenberth hadn't done sufficient research to back up the provocative claims. Some started new studies aimed at testing his claims.

In the July 31, 2005, online edition of the scientific journal *Nature*, Kerry Emanuel, a tropical meteorologist at Massachusetts Institute of Technology, published results of a complicated re-examination of historic data on wind speed and duration for North Atlantic and Western North Pacific storms. Hurricane damage increases exponentially as wind speeds rise, meaning that a hurricane with winds of 148 miles per hour may produce as much as 250 times the damage of a hurricane with 74 mph winds, according to the National Oceanic and Atmospheric Administration.

To calculate the total power generated over a storm's lifetime, Dr. Emanuel multiplied each hurricane's maximum sustained wind speed by itself and then multiplied that result by the wind speed again, a calculation known as cubing. Then he factored in how many hours the storm lasted.

Dr. Emanuel says he used scientifically accepted formulas to adjust for years when wind-speed data are most likely to contain errors, particularly in Atlantic storms from 1949 to 1969, when it is thought speed was overestimated. The calculation showed that the intensity of storms had essentially doubled in the past 30 years. He attributed growing hurricane intensity and destructive power to rising water temperatures that he said were "at least partially" the result of human activity.

At the same time, Dr. Curry and Peter Webster, who is also at Georgia Tech, set out specifically to investigate Dr. Trenberth's assertions. Dr. Webster had co-written a paper in 1998 with Dr. Gray and nine other scientists in which they didn't find the connections Dr. Trenberth claimed.

Much of past research on hurricanes had been limited to storms in the Atlantic, which spawns those that hit the U.S. The Georgia Tech researchers, along with Dr. Holland, broadened their scrutiny to all hurricanes -- known as tropical cyclones and typhoons in the Pacific and Indian oceans -- anywhere in the world since 1970.



***Judith A. Curry***

"It's not rocket science," says Dr. Curry, 52, who says the researchers counted the number of Category 4 or 5 storms, or those with sustained wind speeds of at least 131 mph. They found that the total number of storms world-wide stayed fairly constant, but the number of intense ones had doubled since 1970. About two weeks after Katrina barreled into the Gulf Coast as a Category 3 storm, an article by Drs. Curry, Webster and Holland laid out their conclusion in the journal *Science*. They say the rise in ocean temperatures isn't related to natural causes and appears to be associated with global warming, most likely related to a rise in greenhouse gases.

Dr. Gray's views on the natural cycle of storms in the Atlantic are strongly supported by the weather establishment. The National Oceanic and Atmospheric Administration, which runs the National Hurricane Center, took the unusual step in November of saying it is the consensus view among NOAA scientists that global warming related to human activity isn't causing either more storms or greater storm intensity. "Increases in hurricane activity are primarily the result of natural fluctuations in the tropical climate system," the statement said.

Most serious weather and climate researchers, including Dr. Gray, agree the planet has gradually warmed in recent decades. Last year was the warmest year since 1880, climatologists at National Aeronautics and Space

Administration's Goddard Institute for Space Studies said recently. All sides also agree 2004 and 2005 were unusually active years for big storms.

The sides disagree about how much global warming is attributable to natural cycles and how much to human activity such as the release of greenhouse gases from burning fossil fuels. Among meteorologists who say humans are behind global warming, many contend there isn't enough evidence to link it to increased hurricane intensity.

Further complicating things: Climate change can be studied based on tree-ring and ice-core samples dating back thousands of years, but specific data on hurricanes has been gathered for only about 150 years. Even that is primarily in the Atlantic. Modern hurricane science began about 60 years ago, when daredevil pilots first flew into the storms. Until then, hurricanes' strength had to be extrapolated from damage and from data collected by ships and on land. Some storms in remote places may not have been recorded at all. Satellites improved the quality of information starting in the 1960s, and meteorologists wrote and rewrote formulas for calculating wind speed in an effort to smooth out the historical record.

Dr. Gray responded sharply to the new research tying hurricane intensity to human-caused climate change, and the once-intimate circle of hurricane researchers erupted in turmoil. In Senate testimony in late September and in papers on his Web site, Dr. Gray said the new conclusions were irreparably flawed by the inferior data of earlier years. He says he had seen weather information being gathered haphazardly when he visited remote Pacific outposts in the 1970s. "The satellites were down or the people weren't trained," he says.

Dr. Gray attacked the Science article on his Web site, agreeing that ocean temperatures were climbing but maintaining that the rise was largely attributable to long-term heating and cooling trends. The rise in water temperature has negligible connection to the hurricanes, he argued. He complained that "the near universal reference to this paper over the last few weeks by most major media outlets is helping to establish a false belief among the general public...that global warming may be a contributing factor" to devastation such as that from Katrina.

Worse, he said in a separate paper on his Web site, flaws in wind-speed calculation are magnified when the numbers are cubed, as in Dr. Emanuel's study. In an email widely circulated among climate researchers in November, Dr. Gray wrote: "How were Emanuel and Webster et al. able to see trends in the global data that the rest of us long-time (tropical-cyclone) researchers presently working on these same data sets do not find?"

Dr. Curry says her study used only data collected since 1970, after satellites were in global use, minimizing the possibility of errors. She says Dr. Gray's prominence in the field has overshadowed critical new research. Meteorologists trained by him had looked at the data for so long and in such a prescribed manner, she argues, that they missed red flags about increasing intensity.

Dr. Holland, the scientist who was supposed to appear with Dr. Gray Tuesday night, once was a student under Dr. Gray. At the Atlanta meteorological conference, he said seasonal forecasts, especially Dr. Gray's, are rarely correct. An ally of Dr. Gray, Chris Landsea, of the National Hurricane Center, presented a critique of the global-warming hurricane theories, but the two scientists weren't in a forum that allowed debate.

Dr. Gray says his forecasts are accurate and improving each year. As for his resistance to the new challenges, it is based on experience and solid science, not his age, he said. "I don't feel I'm fossilized. If half my ex-Ph.

D. students say I'm senile, then I'll quit. They have not."

Scientists on both sides say they expect follow-up studies proving they are right to be published before the next hurricane season starts in June. Drs. Trenberth and Emanuel are submitting separate studies to major journals arguing that the influence of natural cycles has been greatly overestimated, a mutinous theory in established hurricane science. Dr. Landsea says he has submitted his own analysis to a major journal confirming the natural ebb and flow of storms argued by Dr. Gray. Both sides are waiting to see which papers will be accepted.

Meanwhile, a new panel discussion featuring the highest-profile hurricane scientists is being planned for an April conference in Monterey, Calif. Drs. Emanuel and Webster already have said they won't participate if Dr. Gray is there.

**Write to** Valerie Bauerlein at [valerie.bauerlein@wsj.com](mailto:valerie.bauerlein@wsj.com)<sup>1</sup>

## **APPENDIX D**

### **William M. Gray Vita**

Professor Gray has worked in the observational and theoretical aspects of tropical meteorological research for more than 50 years, much of this effort going to investigations of meso-scale tropical weather phenomena. He has specialized in the global aspects of tropical cyclones for his entire professional career. He studied under Professor Herbert Riehl who arranged his early reconnaissance flights into hurricanes in 1958. He has been involved with studies of broad-scale cumulus interactions and has extensively studied the processes associated with tropical cyclone structure, development, and movement. Numerous satellite-based studies of tropical weather systems have also been accomplished. Current areas of research include: 1) tropical cyclone structure, movement and intensity change; 2) seasonal prediction; 3) meso-scale tropical weather systems, 4) diurnal variability of tropospheric vertical motions and 5) ENSO variability. Professor Gray has made Atlantic basin seasonal hurricane forecasts for the last 25 years. He was a pioneer in developing these types of forecasts. In recent years he has also been performing research of the causes of global climate change and the possible role of humans in such changes. He is a skeptic to the hypothesis that humans are the primary cause of the global warming we have seen in recent years.

#### **EDUCATION:**

B.A. George Washington University (1952)

M.S. University of Chicago (1959), in Meteorology

Ph.D. University of Chicago, Dept. of Geophysical Sciences (1964)

#### **METEOROLOGICAL EXPERIENCE:**

Weather Forecasting duty as Air Force Officer, 1953-1957

Research Assistant, Dept. of Meteorology, Univ. of Chicago, 1957-1961

Faculty of Dept. of Atmospheric Science, Colorado State University, 1961-present

Professor, 1974 to 2004

Professor Emeritus, 2005 to Present

#### **ABBREVIATED SUMMARY OF PI'S PROFESSIONAL ACTIVITY:**

Advisor of 50 successful MS (theses) graduates and 20 successful Ph.D. graduates in Atmospheric Science, eight of whom have received AMS awards as students. Panel Member - U.S.-Japan Mutual Science Program (Panel 7-Tropical Storms) - 1964-1969; Panel Member - American Meteorological Society Committee on Hurricanes and Tropical Meteorology 1968-1973, 1978-1981. Chairman 1987-1990; Advisor - U.S. GATE Meso-scale and Cumulus Sub-Programs 1969-1972; Panel Member - USAF Scientific Advisory Board on Tropical Cyclone Aircraft Reconnaissance (1973-1974); USAF Reserve Officer - 1957-1973; U.S. Representative - WMO Working Group on Tropical Meteorology (1975-1988); Co-organizer of three-week NCAR GATE Workshop (summer, 1977); Chairman, Organizing Committee for first WMO International Workshop on Tropical Cyclones, Bangkok, Thailand, 1985.

**AWARDS/HONORS:**

Fellow, American Meteorological Society; CSU "Jack E. Cermak" Graduate School Award for Outstanding Adviser (1992); Co-recipient of AMS Banner I. Miller Award (1993); AMS Jule L. Charney Award (1993); Neil Frank Award of the National Hurricane Conference (April 14, 1995), "for pioneering research into long-range hurricane forecasting and for developing a better understanding of how global climatological conditions shape the creation and intensity of tropical cyclones"; Invited lecture for Eighth IMO Lecture to the 12th WMO Congress, Geneva, June, 1995. (This is an honorary award given to senior scientists in recognition of lifetime research achievements; ABC Television "Person of the Week", September, 1995; Man of Science Award by the Colorado Chapter of Achievement Reward College (ARC) Scientist (1995).

**PUBLICATIONS & RESEARCH REPORTS:**

Over 80 published papers and 60 more extensive research reports.

Hundreds of Conference talks and conference proceedings.

Papers available on CSU website (<http://tropical.atmos.colostate.edu/>)

**Awards Won by Gray's Students for CSU Project Research:**

(1) D. Shea received first (1972) CSU Dept. of Atmos. Sci. Christian Gallet Award. (2) W. Frank received the AMS 1980 Banner I. Miller Award. (3) E. Nunez received the 1980 Max Eaton Prize. (4) G. Holland was a recipient of the 1982 Max Eaton Prize. (5) R. Merrill was a recipient of the 1984 Max Eaton Prize. (6) G. Holland received the AMS Banner I. Miller Award in May 1985. (7) C. Weatherford was the recipient of the 1987 Max Eaton Prize. (8) C. Landsea was the recipient of the 1991 Max Eaton Prize (9) and Co-recipient of the 1993 Banner I. Miller Award. (10) M. Eastin won the AMS Max Eaton Prize and our Department's Herbert Riehl award for research on the PI's project. (10) M. Eastin received the 2002 Max Eaton Prize (11).

**W. M. Gray's Graduate Students: Name, Year of Graduation and Degree**

Bruce Mendenhall (1967) – M.S.  
 M.S. Raul Lopez (1968)--M.S.  
 Ronald Wachtmann(1968)--M.S.  
 James Sartor (1968)--M.S.  
 Thomas Wills (1969)--M.S.  
 Knox Williams (1970)--M.S.  
 Dennis Shea (1972) - M.S.(1)  
 Raul Lopez (1972)--Ph.D.  
 Ray Lee Hoxit (1973)--Ph.D.  
 William Frank (1973)--M.S.  
 Dave Novlan (1973)--M.S.  
 Robert Maddox (1973)--M.S.  
 Greg Walters (1975)--M.S.  
 John George (1975)--M.S.  
 Rodolpho Ramos (1975)--M.S.

Robert Jacobson (1975)--M.S.  
 Gary Foltz (1976)--M.S.  
 Steve Erickson (1976)--M.S.  
 William Frank (1976)--Ph.D.(2)  
 Raymond Zehr (1976)--M.S.  
 Charles Arnold (1977)-- Ph.D.  
 Jean Dewart (1977)--M.S.  
 Pamela Grube (1978)--M.S.  
 John McBride (1979)--Ph.D.  
 William Fingerhut (1980)--Ph.D.  
 Edwin Nunez (1980)--Ph.D.(3)  
 Ken Dropco (1981)--M.S.  
 Greg Holland (1981)--M.S.  
 Cheng-Shang Lee (1981)--M.S.  
 Geoff Love (1982)--Ph.D.

Robert Merrill (1982)--M.S.(5)  
 Johnny C.L. Chan (1982)--Ph.D.  
 Greg Holland (1983)--Ph.D.(4) (6)  
 Cecilia Askue (1984)--M.S.  
 Clifford Matsumoto (1984)--Ph.D.  
 Candis Weatherford (1985)--M.S.  
 Robert T. Merrill (1985)--Ph.D.  
 Cheng-Shang Lee (1986)--Ph.D.  
 Patrick Lunney (1987)--M.S.  
 Candis Weatherford (1987)--Ph.D.(7)  
 Michael Middlebrooke (1987)--M.S.  
 Joel D. Martin (1988)--M.S.  
 Daniel N. Shoemaker (1989)--M.S.  
 Chris Collimore (1989)--M.S.  
 Dan B. Mundell (1990)--M.S.  
 Stephen Hodanish (1991)--M.S.  
 Stephen Hallin (1991)--M.S.  
 Christopher W. Landsea (1991)--M.S.

Raymond Zehr (1992)--Ph.D.  
 Michael E. Fitzpatrick (1992)--M.S.  
 John A. Knaff (1992)--M.S.  
 Edward B. Rodgers (1992)--Ph.D.  
 Christopher W. Landsea (1994)--Ph.D(8)(9).  
 Gary B. Kubat (1995)--M.S.  
 Patrick J. Fitzpatrick (1995)--Ph.D.  
 Carl A. McElroy (1996)--M.S.  
 Stephen B. Cocks (1997)---M.S.  
 John A. Knaff (1997)---Ph.D.  
 Matthew D. Eastin (1999)---M.S.  
 Kelly M. Findeisen (1999)---M.S.  
 Robert N. LeeJoice (2000)---M.S.  
 Steven E. Vilpors (2001)---M.S.  
 Eric S. Blake (2002)---M.S.  
 Philip J. Klotzbach (2002)---M.S.



**Science & Public Policy Institute**

*"Science-based policy for a better world."*

**Robert Ferguson**

*SPPI President*

bferguson@sppinstitute.org

202-288-5699

P.O. Box 209

5501 Merchants View Square

Haymarket, VA 20169

www.scienceandpublicpolicy.org